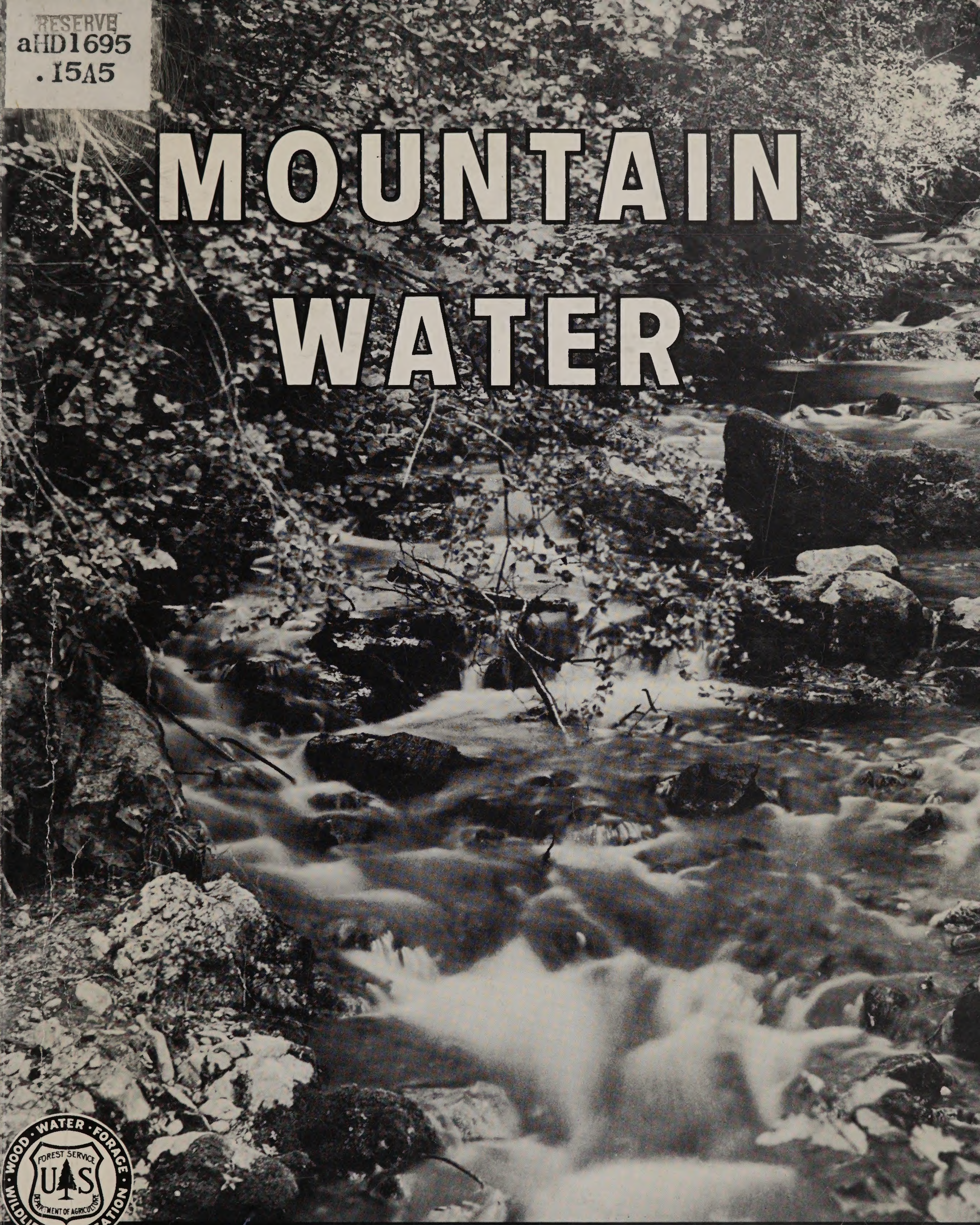
Historic, Archive Document

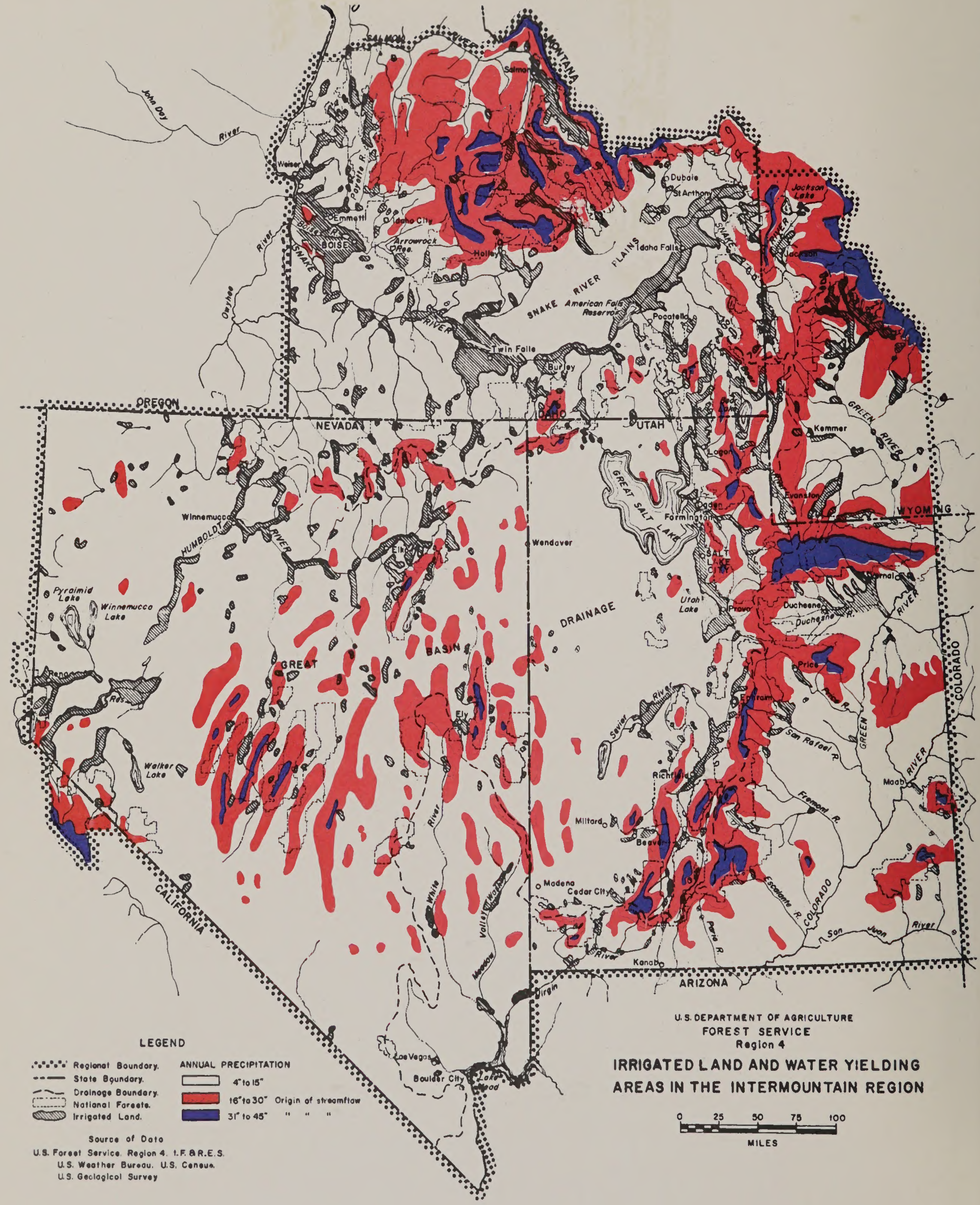
Do not assume content reflects current scientific knowledge, policies, or practices.

MOUNTAIN WATER



INTERMOUNTAIN REGION • FOREST SERVICE

U.S. Department of Agriculture


U.S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE
Region 4
IRRIGATED LAND AND WATER YIELDING AREAS IN THE INTERMOUNTAIN REGION
0 25 50 75 100
MILES
LEGEND
Regional Boundary.
State Boundary.
Drainage Boundary.
National Forests.
Irrigated Land.
ANNUAL PRECIPITATION
4" to 15"
16" to 30" Origin of streamflow
31" to 45" " " "
Source of Data
U.S. Forest Service. Region 4. I.F.&R.E.S.
U.S. Weather Bureau. U.S. Census.
U.S. Geological Survey
OREGON
NEVADA
IDAHO
UTAH
WYOMING
MONTANA
COLORADO
ARIZONA
CALIFORNIA
GREAT BASIN DRAINAGE
GREAT SALT LAKE
SNAKE RIVER PLAINS
SNAKE RIVER
HUMBOLDT RIVER
GREEN RIVER
COLORADO RIVER
SALMON RIVER
John Day River
Owyhee River
Weiser
Emmett
Idaho City
Boise
Arrowrock Res.
Salmon
Dubois
St Anthony
Idaho Falls
Jackson Lake
Jackson
American Falls Reservoir
Pocatello
Twin Falls
Burley
Kemmer
Evanston
Logan
Ogden
Farmington
Salt Lake City
Wendover
Winnemucca
Elko
Pyramid Lake
Winnemucca Lake
Reno
Walker Lake
Ely
Utah Lake
Provo
Duchesne
Duchesne R.
Price
Ephraim
San Rafael R.
Sevier River
Richfield
Moab
Fremont R.
Millard
Beaver
Modena
Cedar City
Escalante R.
Paria R.
Kanab
San Juan River
Virgin
White River
Las Vegas
Boulder City
Lake Mead

MOUNTAIN WATER

Prepared by:
A. Russell Croft, formerly Head
Branch of Watershed Management,
U. S. Forest Service, Ogden, Utah.
and
Reed W. Bailey, formerly
Director, Intermountain Forest
and Range Experiment Station,
U. S. Forest Service, Ogden, Utah.
Under contract with
Intermountain Region,
U. S. Forest Service, Ogden, Utah.
May, 1964

Cover Photo: City Creek, Wasatch National Forest.

Back Cover Photo: Ogden Valley and Pineview Reservoir, Cache National Forest.

CONTENTS

	Page
The Land in Which We Live	4
Climate	7
Streamflow	9
The Soil and Plant Mantle	13
Our Civilization Under the Ditch	17
Man and His Environment	17
Settlements on Mountain Streams	18
Watershed Mantle Breakdown	19
Balance Disturbed by Man	19
Sedimentation	22
Echoes From the Past	28
How Watersheds Function	29
Watershed Research	29
Results of Research	32
Water Consumption by Vegetation	39
Analysis of Some Destructive Floods	44
Repairing Damaged Watersheds	53
What Does Restoration Involve?	54
Restoration Measures	55
A Look Ahead in Wildland Management	58
The Greatest Good	58
Needs of the Future from Wildlands	58
Conservation With Use	59

FOREWORD

The National Forests of the Intermountain Region yield an estimated 27 million acre-feet of water annually or about nine inches per acre of watershed. This amounts to about 75% of the total water yield in the Region and plays a major role in satisfying the needs of approximately 70 hydroelectric plants, 200 storage reservoirs, and 190 towns and cities. And, in the foothills and valleys, most of our irrigation agriculture depends on this water.

One of the major purposes for which Congress established the National Forest System under the Organic Act of 1897 was to "secure favorable conditions of water flows." Significant National Forest legislation in 1960, called the Multiple Use-Sustained Yield Act, reaffirms this purpose but goes much further. It also directs that the National Forests shall be managed for multiple use — for water, wildlife, recreation, timber, and forage. It directs that management of these five uses shall be on a sustained yield basis. Thus, the legislative mandate for watershed management and other uses of the National Forests is specific and unmistakable.

Most of the National Forest land within the Intermountain area is valuable as watersheds. These public properties require careful and skillful management if they are to contribute most effectively to the long-time needs of the people of this Region and the Nation. While much of the National Forests are in satisfactory condition, some areas have lost their ability to properly receive and dispose of the water which falls upon them. Overuse by domestic livestock over extended periods has contributed to watershed depletion as have some improperly located roads, logging on steep slopes where erosion control has been inadequate, excessive big game populations, and inadequate design in water impoundments and transmission structures. The maintenance of or re-establishment of hydrologic conditions which will insure control of water is a major resource management objective. To achieve this will require certain changes in management on some National Forest lands, coupled with expensive rehabilitation measures on seriously depleted areas.

People must know and appreciate that watersheds need careful and skillful management to keep them functioning properly. All of us must understand the need for curative treatment to restore watershed lands to a satisfactory condition when necessary. Public awareness of and concern about watershed problems and management needs are imperative in a democracy if watersheds are to be managed for the benefit of all the people today and for future generations — and they must be so managed.

This publication was prepared to help people gain a better understanding of how watersheds function. It assembles in one place much of what has been learned from research and management about man's relationship to his environment and his responsibility for maintenance of productive watersheds in the Intermountain West. It records also some of the authors' views and conclusions relating to watershed management that perhaps are not documented in other publications. I am pleased that authorities such as A. Russell Croft and Reed W. Bailey undertook this task. Each is eminently qualified; each has fulfilled a distinguished career in the field of watershed research, management, and restoration.

Floyd Iverson

Regional Forester

THE LAND IN WHICH WE LIVE

Occupancy of the land and development of a civilization — a culture — in the Intermountain West have been difficult tasks. The concern has been largely with mountain water and problems connected with its use and conservation. When the white man came to the region to establish his home and use the resources of the land he found an environment that was strange to him, difficult to understand, and rigorously demanding. The landscape of the area was dominated by mountain ranges and valleys and the mountain-valley relationship was largely responsible for the nature of such various elements of the environment as slopes and aspect of the land, climate, creeks and rivers, soils and vegetation.

The topography of the area largely determines the precipitation pattern over the land just as general air circulation determines it in time. The Sierra Nevada-Cascade Mountain crests rising to a maximum elevation of about 14,000 feet act as a barrier to eastward-moving storms and are responsible for much of the relatively heavy precipitation on their west slopes and the aridity of the Great Basin and the Columbia River Plateau. Similarly each successive mountain range eastward acts in turn to increase precipitation on the western slopes and to make for greater aridity on the slopes and valleys to the east. It is not uncommon to find some valleys receiving only 4 to 5 inches of precipitation while mountain slopes less than 20 miles away receive in excess of 40 inches. The influence of topography on precipitation is shown in Fig. 1, which gives mean annual precipitation values for certain points along a topographic profile from San Francisco to Denver.

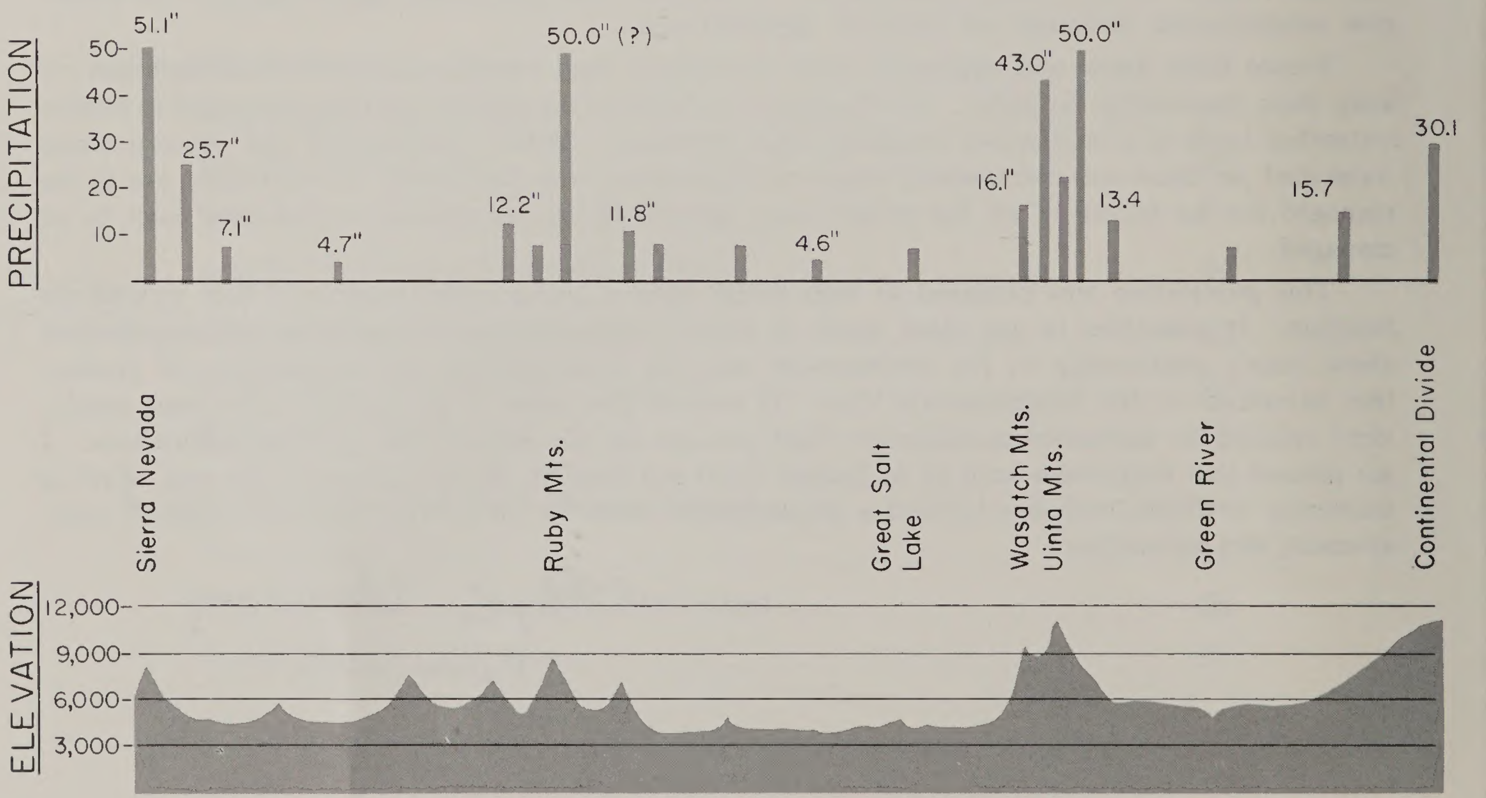


Figure 1. — Precipitation at some mountain and valley stations along a line from San Francisco to Denver.

Topography also greatly modifies temperatures. Some valleys are not free of frost for a sufficiently long time to grow anything but the hardiest grains and forage, while others in the same latitude but at lower elevations have summer growing seasons warm enough and long enough to permit the raising of late maturing crops such as sugar beets, fruits, and corn.

The mountains have a great variety of climatic situations, due to differences in aspect of the various slopes and differences in elevation. The temperature may range from high subtropical near the base to subarctic on the high slopes and basins. The high mountains are cool in summer and covered with snow in the winter and the growing season is short, which creates a serious problem of use, especially grazing of the forage.

Figure 2.— Great Salt Lake Valley and Wasatch Mountains north of Provo Canyon, Utah.

The great and abrupt differences in precipitation induced by the topography not only give rise to the arid valleys but also to the humid "islands" wherever mountain masses project to a substantial height above the valley floor. Most of these "islands" receive enough precipitation to support stands of ponderosa and lodgepole pine, quaking aspen, Engelmann spruce, Douglas-fir, and alpine fir as well as a wide variety of shrubby and herbaceous vegetation which constitutes the important resource of forage for livestock and game.

This greater amount of precipitation that falls on the humid mountains is largely responsible for generating the streams that flow into or out of the region. Moreover, snow in the late fall and winter, stored for spring and summer melting, makes possible and maintains the summer flow of most streams.

The importance of the relationship between cool humid mountains and warm arid valleys cannot be too strongly stressed. It determined the pattern of settlement of the arid west and was responsible for the development

of modern irrigation agriculture — a system of farming where crops are not dependent upon precipitation that falls on the cultivated lands but upon that which accumulates on the forest and rangelands in the mountains.

The early settlers, for the most part, established their homes and industries at the mouths of the canyons or along the base of mountains where mountain waters were available. These locations were selected partly because of availability of fertile soils and favorable temperatures but primarily because the adjacent mountains provided sources of timber for their homes, forage for livestock, and above all, water for sustaining life throughout the dry summer months on the valley floors. Later, engineering developments were introduced in the form of storage reservoirs and elaborate canal systems. Important agricultural enterprises, significant industries, and large populations in and beyond the Intermountain West were established and more are to come. These are all largely dependent upon the stored mountain waters.

The relationship between the mountains and the valleys is illustrated by the Wasatch Mountains and Salt Lake Valley, which is impressively described in the following quotation from Dr. Walter P. Cottam:

> *Every citizen interested in Utah as home for himself and especially for his children should take a one-day, conducted excursion to this mountain top (Wasatch). The view alone is rewarding and the lessons to be learned there are impressive. A long narrow strip of green earth checkered by roads and fences, lies far below as if squeezed between the solid mountain base and the faded blue of the Great Salt Lake. Beyond this the endless tracts of desert waste merge with the sky. Inevitably the eye returns to this strip of green. Smudgy haze over the settlements below marks the position of each town precisely at the mouth of some major canyon. What a vantage point to see and know how the existence of man is wedded to the hydrology of these hills! If the streams discharge their floods, where can man retreat? If they fail in their life-giving fluid, where can he quench his thirst? (Cottam 1961)*

Although the first extensive dependence on mountains was for irrigation water, this dependence has extended far beyond and is basic to our present and future economic development. Important as water is, other mountain resources such as timber, forage, and recreation contribute importantly to the economy and well-being of the region and the Nation.

Past experience of the people who settled this Intermountain Region had not prepared them for an easy adjustment to this environment. They had little knowledge to guide them in the use and conservation of the available resources. The uncompromising realities of nature, the uncertain precipitation and streamflow, the precariously situated mountain soils, the hazards of grazing the steep slopes and the subarctic basins, and the critical aridity of the valleys could not be disregarded without disaster. Mistakes were made and harmony between man and his environment has never been fully attained.

Subsequently, knowledge was gained through experience and scientific research which provided facts and principles to guide in the safe use of the mountain resources and to correct many of the past mistakes. However, a greatly accelerated management program, based upon facts already at hand and a continuing program of education and research, will be required to insure a continuation of the way of life in the Intermountain Region that has been organized around the resources of the mountains.

The need to understand the environment in which we live and work was dramatically described by Dr. Isaiah Bowman, then President of Johns Hopkins University when he said:

> *If we lived in a desert and our lives depended on a water supply that came out of a steel tube, we would inevitably watch that tube and talk about it understandingly. No citizen would need to be lectured about his duty towards its care or spurred to help if it were in danger. Teachers of civics in such a community might develop a sense of public responsi-*

bility not only by describing the remote beginnings of the commonwealth, but also how that tube got built, how long it would last, how vital the intake might be if the rainfall on the forested mountains nearby ever changed in seasonal habit or amount. It would be a most unimaginative person, or a stupid one, who could not see the vital relation between the mountains, the forests, that tube and himself. (Bowman 1937)

CLIMATE

To understand more fully the problems that occur in the use and conservation of mountain resources, knowledge and understanding of the nature of some of the important factors is necessary.

PRECIPITATION

The amount of precipitation is determined largely by topography. The Wasatch Mountains, for example, receive from 30 to 60 inches of precipitation annually, but some of the arid valleys 40 miles west receive only 4 or 5 inches. Generally, streamflow originates above about 5,000 feet elevation where there is a surplus of precipitation after the growth requirements of plants have been satisfied along with losses by evaporation from the soil, snow, and vegetation.

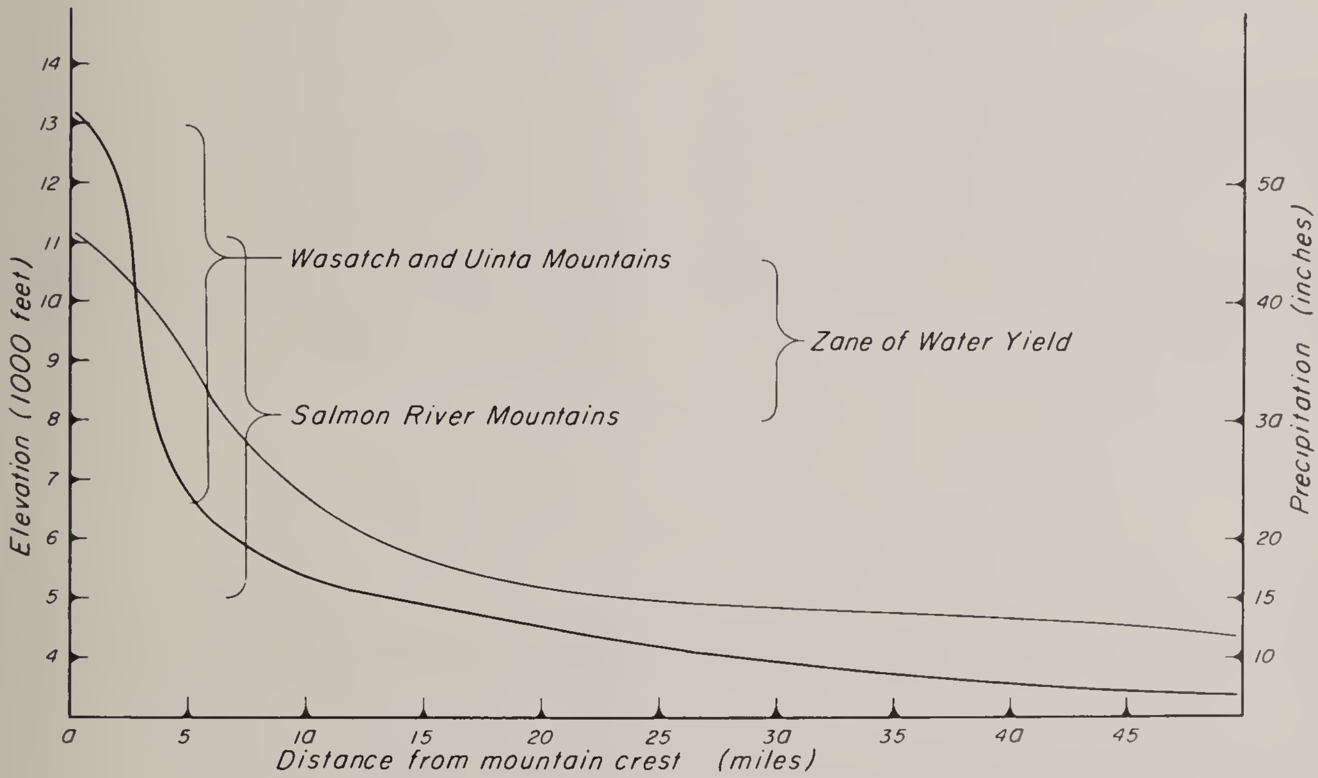


Figure 3. — The approximate relation of total precipitation to elevation and distance from the mountain crest. (Utah and Idaho)

In Utah the water-yielding areas of our humid mountains are above 6,500 feet elevation and amount to about 10,000,000 acres. In the Salmon River Mountains of Idaho, on the other hand, the water-yielding zone extends downward to about 5,000 feet elevation. These elevation - precipitation - wateryield relationships are shown in Fig. 3.

Precipitation Fluctuation—Fluctuation in precipitation is illustrated by the rainfall records from Manti, Utah, elevation 5,575 feet — one of the longest records in Utah. Precipitation in some years is only half of "normal" or average, but 50 percent above normal in other years. (See Fig. 4)

When the Manti record is plotted as a moving average by ten-year periods (1894-1903; 1895-1904, etc.), some interesting upward and downward trends in precipitation are shown. For example, beginning with an annual average of about ten inches of rainfall for the period 1894-1903, the trend was gradually

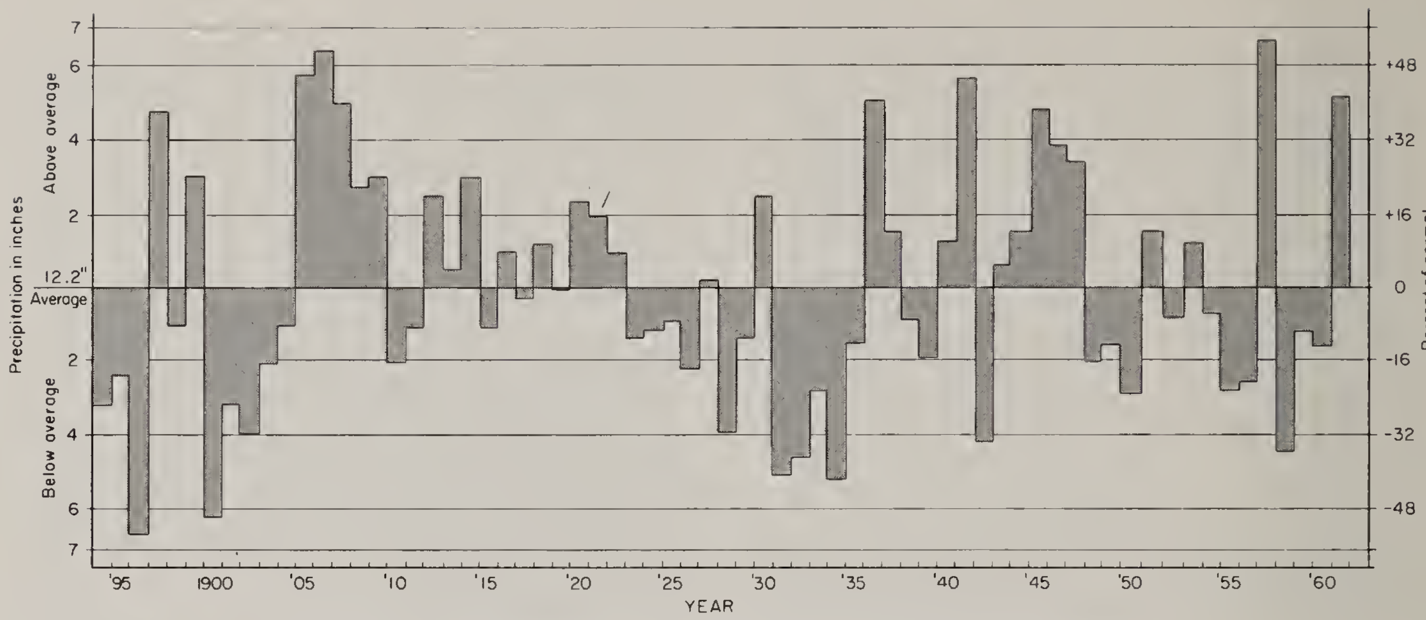


Figure 4. — Fluctuations in total annual, and the average annual precipitation 1895 to 1962. (Manti, Utah)

up until the annual average rainfall for the period 1905-1914 was about 15 inches. Then a general down-trend occurred which resulted in about ten inches of precipitation annually for the period 1926-1935. If a 500-year record were available for Manti, it is quite possible that fluctuations in the ten-year average precipitation would be larger than those shown for the present 68-year record. In other words, it is quite possible that we have not lived in the Intermountain West long enough to have experienced the full range of perfectly "normal" high and low rainfall years or groups of years and the effect they could have on streamflow.

Figure 5. — Trends of total annual precipitation by ten-pear periods at Manti, Utah.

"Cloudbursts"—The term "cloudbursts" has gained common usage in the West to describe certain summer rainfall phenomena. The term is frequently associated with the results of rainfall rather than knowledge of the rainfall itself. For example, flooding of low-lying business and residential areas during a rainstorm is frequently referred to as the result of a "cloudburst," when actually the flooding may be caused by runoff from roofs, cement

driveways, sidewalks, and streets from only modest rainfall.

Likewise, a sediment-laden summer flood from the mountain is cited as evidence of a "cloudburst" when it may be only a modest rainstorm on steep slopes from which too much vegetation has been removed, allowing quick surface runoff.

We do, however, have periods of short intense rainfall, particularly during July and August, which are normal to the summer rainfall pattern. They may or may not cause flash floods, depending on the capacity of the land surface to absorb all or part of the rain as it falls.

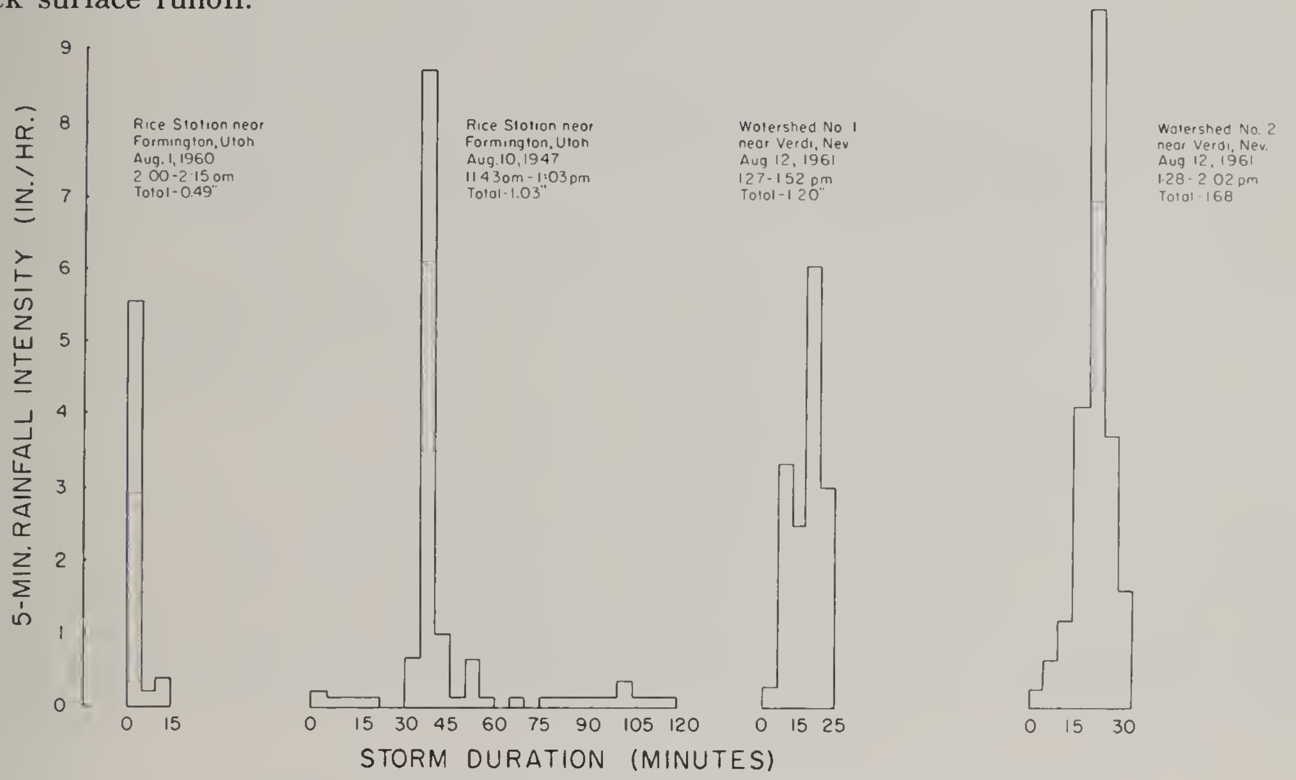


Figure 6.--Records of three intense summer rainstorms in the Sierra Nevada and Wasatch Mountains.

The chart shows the history of three cloudburst-type rainstorms; two at the Davis County Experimental Watershed in Utah, elevation 7,000 feet, and the other at the Dog Valley Experimental Area near Verdi, Nevada. At Davis County, the maximum intensity of rainfall occurred during the first five-minute period of a storm in August 1960, but not until after 40 minutes of gentle rainfall in 1947. At two raingages on the Dog Valley Area, the intense fall occurred at the beginning of the storm of August 12, 1961. The difference of one minute in starting time of the two records is the time required for the storm front to travel about ½ mile from Watershed No. 1 to Watershed No. 2.

The Mountain Snowpack — In the humid mountains from 60 percent to 80 percent of the annual precipitation falls as snow from about October 1 to April 1 and except for limited melting, remains in storage as snow and ice. In Utah, this makes a spectacular snowpack which covers about 10,000,000 acres above about 7,000 feet elevation. In a year of average precipitation, this frozen mass contains roughly about 15,000,000 acre-feet of water. Water from the melted snow (about 0.5 to 2.0 inches of water per day) enters the soil where part of it is stored, later to be used in plant growth, and the balance passes on through the soil to streams and ground water.

STREAMFLOW

Water that flows from the mountains to the arid valleys is precipitation not used on the mountain to grow trees, shrubs, and grasses or lost by evaporation from vegetation and soil and snow surfaces. Thus, streamflow is a "residual" of the precipitation, or water that is left after these uses and losses.

Figure 7. — The winter's snowpack in high mountains and plateaus is the source of water for the arid valleys. (Great Basin Experimental Area, Utah)

The relation of precipitation to water yield may be expressed by a simple formula:

$S = P - (U + L + D)$ where:

S = Streamflow

P = Precipitation

U = Uses by vegetation

L = Losses by evaporation from snow, soil, and vegetation

D = Deep seepage

Streamflow characteristics are a result of such normal forces and factors as climate, geology, topography, and the soil and plant mantle, all of which have operated through the ages to produce today's streams. Since precipitation increases approximately four inches for each 1,000 feet increase in elevation, the largest water yields come from the highest mountains.

SEASONAL AND ANNUAL FLUCTUATION

Differences in the amount of streamflow from season to season and from year to year are striking and indeed economically significant features of mountain streams. Highest streamflow comes during May and early June, near the end of the snowmelt period and reaches low flow in late summer when the demand for water for most uses is greatest. Streamflow fluctuates also from year to year; some years water will be quite adequate to supply the needs that have developed for it; and then, in another year, the supply may be so short as to require drastic water rationing. Many factors contribute to this annual fluctuation, but the amount of precipitation on the watershed is by far the most important. Two watersheds, Halfway Creek on the Davis County Experimental Watershed, Utah and Ephraim Creek at Ephraim, Utah, illustrate this relationship.

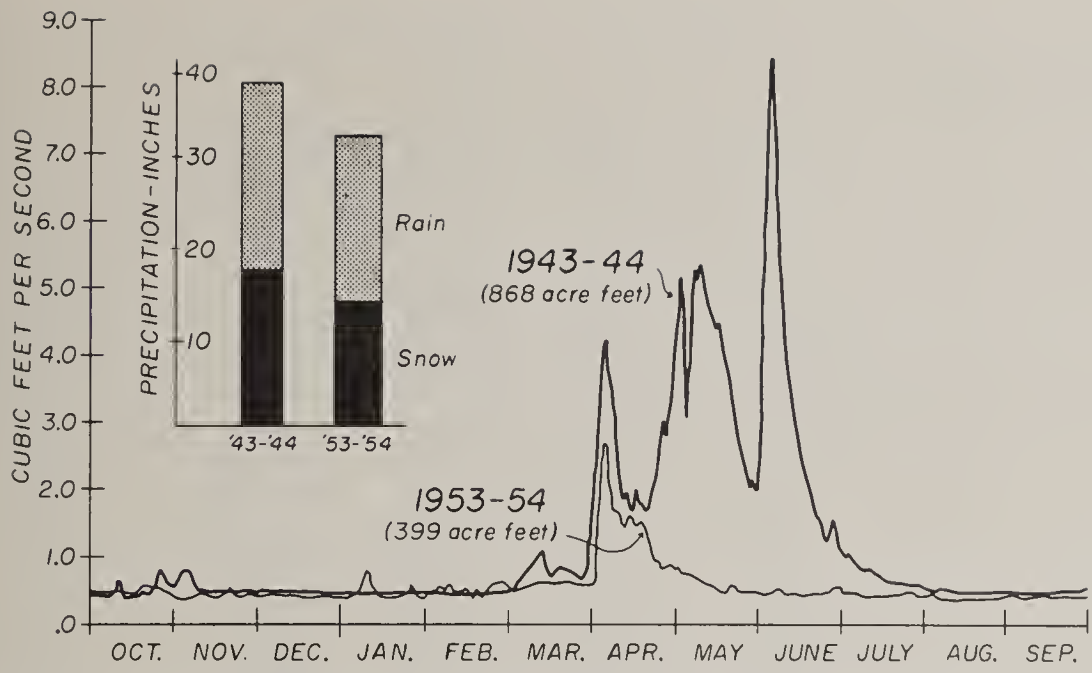


Figure 8. — Differences in annual water yield, 1943 and 1953. (Halfway Creek drainage, Davis County Experimental Watershed, Utah)

Halfway Creek Drainage — Streamflow records from Halfway Creek drainage, comprising 464 acres of brush-covered land, show the differences in water yield from year to year. In the water year 1944 (Oct. 1, 1943 to Sept. 30, 1944) 38.09 inches of precipitation produced 868 acre-feet of streamflow. But in water year 1954, a year when precipitation was only 32.21 inches, water yield dropped to 399 acre-feet, only 46 percent as much as in water year 1944.

Ephraim Creek Drainage — Ephraim Creek Drainage, a 16,680 acre brush, grass, and timber-covered watershed east of Ephraim, Utah, illustrates relationships of precipitation and streamflow over a 20-year period, 1941-1961. Table 1 gives precipitation at three measuring stations and total streamflow in acre-feet and in inches depth for easy comparison with precipitation. In the water year 1959, annual precipitation was only 21.48 inches or about 56 percent of the 38.22 inches in the water year 1952; but streamflow in 1959 was only 25 percent of that in 1952.

The most striking contrast in the relation of precipitation and streamflow occurred in the water years (October 1 to September 30) 1961 and 1962. The anomaly between precipitation and runoff data for these water years is quite readily explainable. Mean precipitation during the last 2 months (August and September) of the 1961 water year was 10.79 inches, about 5.4 times greater than the two-month average of 2.00 inches for the other 21 years of the record.

This unusually heavy rainfall had practically no effect on water yield in the 1961 water year because it was largely stored in the dry soil which is a common condition at the end of the growing season in September and, therefore, produced little if any seepage flow to the stream. Unlike the other years, probably as much as 8.79 inches (10.79 inches — the 2 inch average for other years) was carried over on October 1, as soil moisture, from the 1961 water year to the 1962 water year. Accordingly, it would be reasonable to reduce the effective precipitation in the 1961 water year by this amount (32.73 inches — 8.79 inches = 23.94 inches).

On the other hand, the carryover of 8.79 inches of water in the soil from the 1961 water year to the 1962 water year would have the effect of increasing the effective 1962 precipitation by that amount (29.79 inches + 8.79 inches = 38.58 inches).

These adjustments accounted for a difference of 14.64 inches in effective precipitation between water years 1961 and 1962, and largely account for the high streamflow in the 1962 water year.

Table 1.—Relation between average annual precipitation and total water yield, Ephraim Creek, Utah

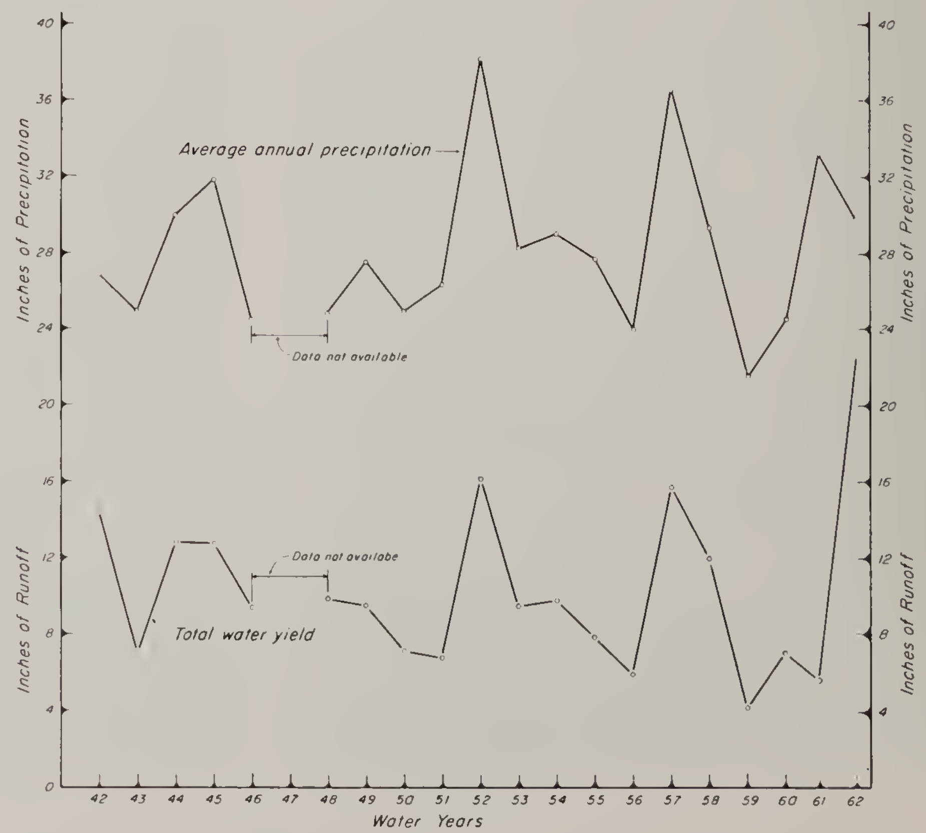
Water Year[2]	Precipitation (inches) 9,950′ Alpine	8,850′ Hdqrs.	7,400′ Oaks	Mean	Runoff[1] Acre Feet	Area Inches
1941					15,029	10.8
1942	30.32	29.32	21.26	26.97	20,162	14.6
1943	28.88	27.34	18.52	24.91	9,534	6.9
1944	34.74	31.55	23.58	29.96	17,910	12.9
1945	34.72	34.90	25.82	31.81	17,764	12.8
1946	29.82	25.79	17.79	24.47	13,053	9.4
1947	Not available					
1948	29.33	25.65	19.33	24.77	13,679	9.8
1949	32.66	30.07	19.93	27.55	13,224	9.5
1950	27.80	27.02	19.90	24.91	9,854	7.1
1951	30.56	28.59	19.91	26.35	9,353	6.7
1952	43.62	41.88	29.16	38.22	22,434	16.1
1953	31.33	31.42	22.00	28.25	13,166	9.5
1954	32.39	31.24	23.40	29.01	13,592	9.8
1955	30.91	30.24	21.84	27.66	10,906	7.9
1956	28.35	24.75	18.26	23.79	8,121	5.8
1957	42.01	38.81	29.15	36.66	21,839	15.7
1958	38.25	30.24	19.47	29.32	16,615	12.0
1959	25.49	22.73	16.23	21.48	5,756	4.1
1960	30.97	25.23	17.35	24.52	9,757	7.0
1961	38.46	34.77	24.96	32.73	7,732	5.6
1962	38.45	29.87	21.05	29.79	31,657	22.8

1/ Corrected for diversions from the Colorado River drainage via Ephraim Tunnel, John August, Dave Madsen, and Twin Springs ditches.

2/ October 1 to September 30.

Precipitation and streamflow data in the above table are shown graphically in the chart below. The close relationship of total precipitation to total streamflow is impressive. Regression analysis indicates that total annual precipitation alone, independent of other factors, is the principal cause of streamflow fluctuation.

Figure 9. Relationship of average annual precipitation and total water yield. (Ephraim Creek Utah)



Streamflow Fluctuates More Than Precipitation

The foregoing discussions of annual streamflow fluctuations of Halfway and Ephraim Creeks show that streamflow changes are not proportional to precipitation: that is a 50 percent decrease or increase in precipitation would not necessarily result in a corresponding change in the amount of streamflow. Actually, with only 50 percent of normal precipitation some streams would dry up because that amount could be consumed by vegetation, leaving no water for streamflow and ground water. Since plant growth consumes practically all available soil moisture in the root zone each summer, the water removed in plant growth must be replaced each spring to bring the soil to its maximum waterholding capacity before water can percolate through to streams. If the amount of water available from precipitation is not enough to saturate the soil, no streamflow will occur. This is one of nature's requirements regardless of whether precipitation is high or low.

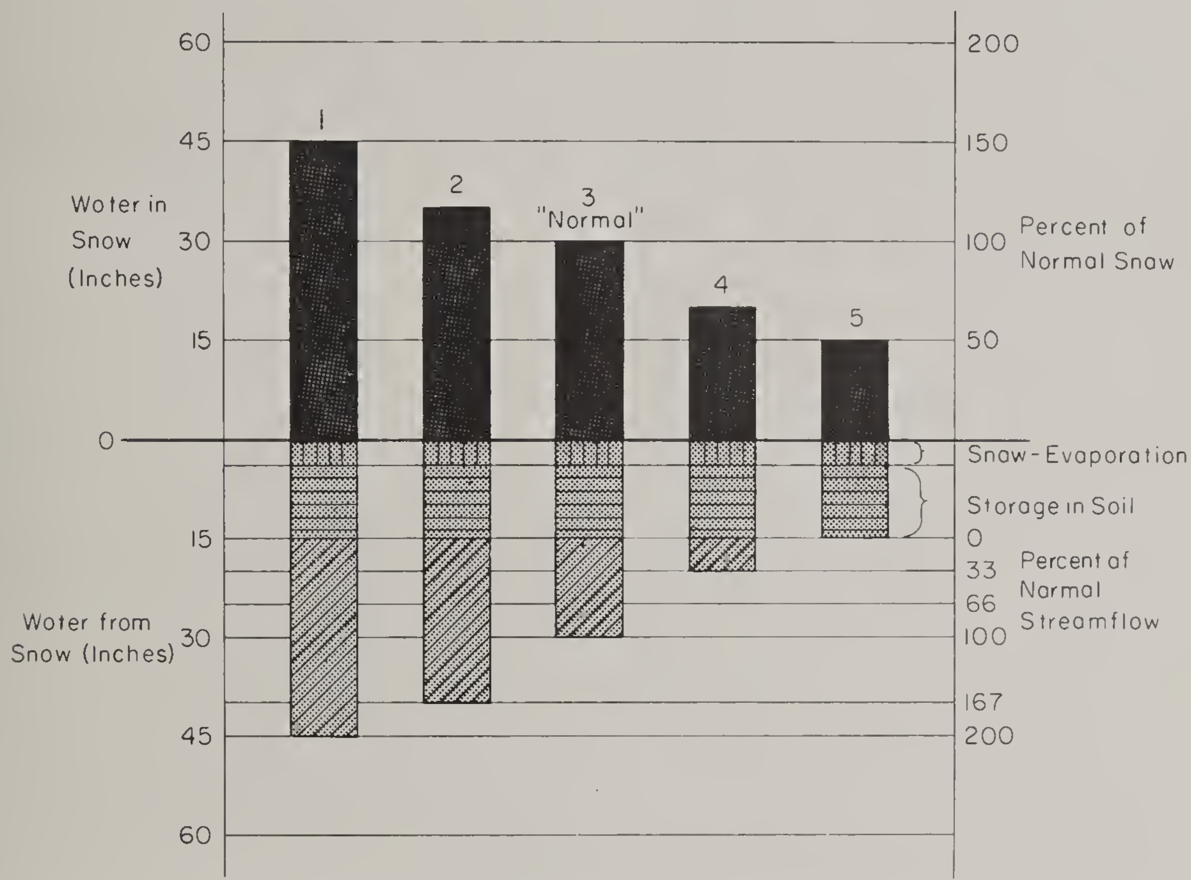


Figure 10. — Annual fluctuation of water yield is not directly proportional to the amount of precipitation.

This principle is illustrated by the accompanying diagram using various amounts of snowpack. For example, if a snowpack of 30 inches (column 3) produces 15 inches of water available for streams, a 15-inch snowpack would provide no water for streams (column 5). On the other hand, an increase in precipitation has just the opposite effect on the amount of water available to streams; a snowpack of 45 inches (column 1) would provide about two times as much water for streams as the 30-inch snowpack.

THE SOIL AND PLANT MANTLE

Of all our inherited watershed resources, the soil mantle is most important. It grows trees, grasses, and shrubs, and is a dominant influence in regulating streamflow. As aptly stated by Bradley (1935):

The soil is the thing;
It tempers the surface climate,
It furnishes water and nutrients for forage and trees,
It infiltrates water from storm,
It is the regulator of streamflow.
Soil is alive — it is dynamic.
We must understand it.

Figure 11.–Plants contribute to soil formation and stability.

Figure 12. — Plant cover and soil stability.

The soils on steep slopes are the product of rock weathering and plant growth throughout the ages. The only way the soil mantle could have been formed on these steep slopes or held in place against the forces of gravity, impact of rain, freezing, thawing, and surface runoff is through the interdependent development of the soil and plant cover.

Anyone who has seen soil being eroded from sprinkling of a newly planted lawn must be impressed with the remarkable stability of the soil and plant mantle on steep watershed slopes that have been subjected to torrential rainstorms through the ages. Loose sand and silt will stand against gravity without support on slopes up to about 69 percent. However, when combined with plant roots and organic matter, soil may be held in place on slopes far beyond the angle of repose for loose material, even above 175 percent.

Soil cannot be formed on steep watershed slopes, nor can it long exist there, without the aid of plants. From the time the first mineral particles were stabilized on rock surfaces — probably by lichens and mosses — on through the age-old processes of soil formation and accumulation, plants have exerted a dominant role. Plants cushion the impact of torrential rains, provide organic matter for development processes, create channels for infiltration and percolation of water, and their roots bind the soil mass together.

Figure 13. — Plant cover and soil stability. The sharp soil profile at the brink of the eroding cliff suggests that soil and cliff are eroding backwards at about the same rate. (Wood River Drainage, Idaho)

Soil stability during the geologic past is illustrated by a steep slope above the Wood River at Hailey, Idaho. Here a soil mantle not more than one foot deep and well covered with vegetation rests on a 100 percent slope (see photo). The soil extends down to the very brink of the steep cliff above the river and shows no sign of oversurface flow of water. Moreover, the sharp soil profile at the cliff's edge strongly suggests that the soil and cliff are eroding backward at about the same rate.

THE SOIL'S GREAT VARIABILITY

Every stable soil has a resilient "armor" which may range from a thick tough cover provided by the litter of trees, shrubs and sedges to a thin easily damaged, less resistant mantle provided by annual grasses or forbs.

"Armor" is an apt term for surface soil cover, for once broken either by natural processes or man's activities, the loose underlying soil is rapidly washed away by rainfall.

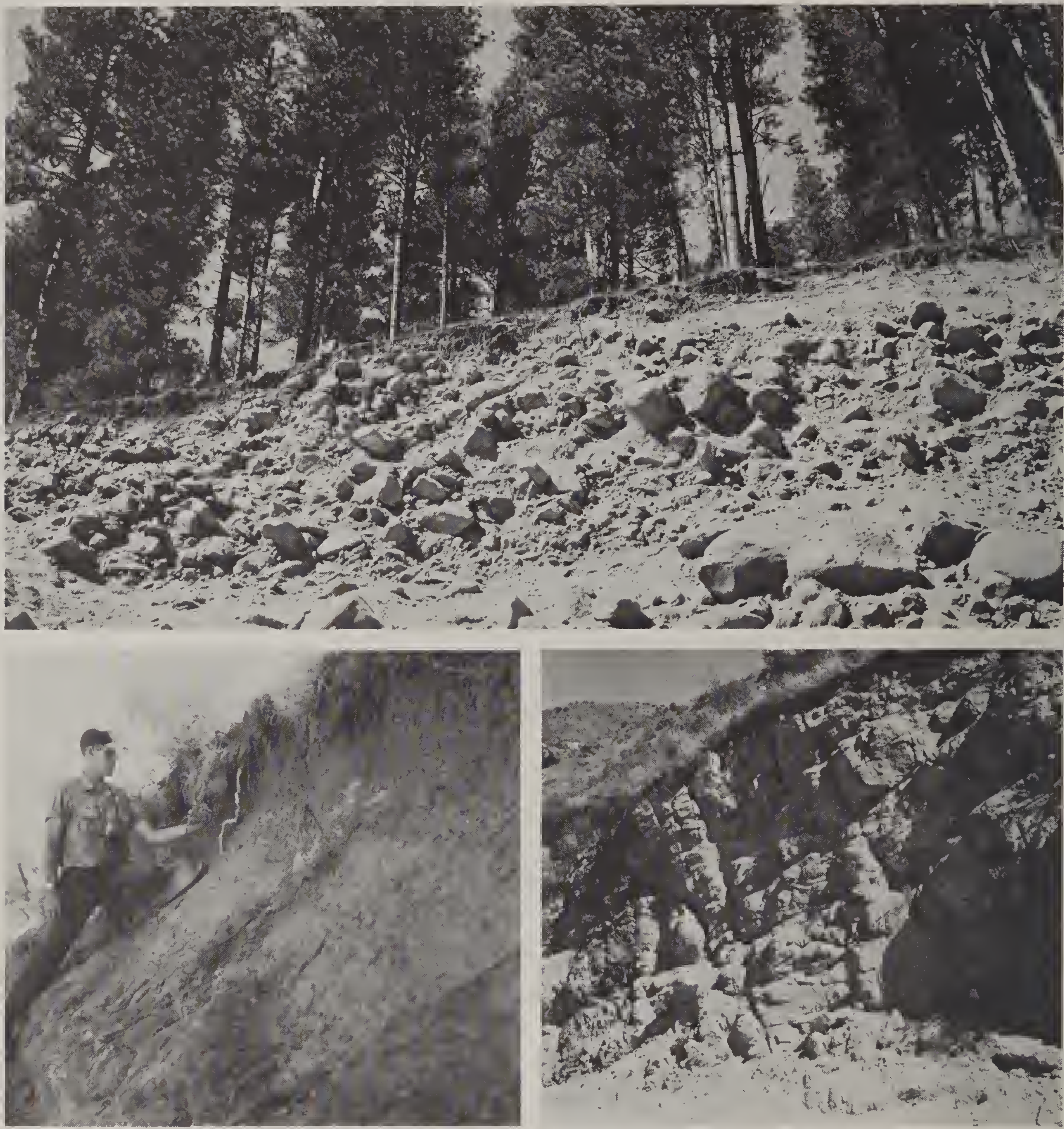


Figure 14. — Mountain soils vary greatly in depth and texture.

Mantle depth also varies greatly; it is only a few inches deep on millions of acres in the Salmon River and Sawtooth Mountains of Idaho and Ruby Mountains of Nevada, but several feed deep on parts of the Wasatch Mountains and the high plateaus. The possibility of damage to thin soils from logging and grazing should be obvious, as compared to such practices on deep soils.

Texture is another very important property of the soil, which may vary from fine relatively impervious silts and clays to coarse gravelly fragments easily permeable to water, but with low waterholding capacity. Figure 14 illustrates some of these variations. They show the soil's remarkable stability when clothed with vegetation, irrespective of tremendous differences in depth and texture.

OUR CIVILIZATION UNDER THE DITCH

MAN AND HIS ENVIRONMENT

Thus far there has been presented a sketch of "the land we live in": its humid mountains and arid valleys, rainfall, the snowpack, streamflow and its fluctuation, and the soil and plant mantle — that magic watershed blanket on which the productive and water-yielding characteristics of our watersheds depend.

The survival of this western civilization — irrigation, agriculture, industries, and cities themselves requires an understanding of the peculiar relationship of man to his environment. Before man entered the picture, streams in this region had definite characteristics of flow. In some instances they were generally clear and flowed with a relatively constant volume; in others, the regimen was marked by great variations in volume and timeliness of flow, and vast differences in sediment content. Regardless of specific differences between streams, however, the most important fact for us to understand is that each stream is the reflection or resultant of such normal factors and forces as the climate, the topography, the geology, and the soil and plant mantle, all of which have been operating through the ages to give rise to definite landforms, specific soils, and characteristic stream channels and streamflow.

Figure 15. — Drainage basins exhibit striking differences in soil and plant cover and in sedimentation. (Farmington Creek, left; Lost Creek, right; Utah)

The striking difference in certain features of mountain watersheds as man found them is illustrated by Farmington Drainage, near Farmington, Utah, and Lost Creek Drainage, a tributary of Provo River above Provo, Utah.

The steep slopes of the 440 acre Lost Creek drainage are largely bare rock with a mantle of soil and plants holding on precariously in only a few patches. Without a soil and plant mantle to dispose of rainfall and snowmelt water, stream discharge has been violent, intermittent, and often debris-laden. An alluvial cone composed of sediments of thousands of mud and rock flows that have occurred during the immediate geologic past has forced the river to the opposite side of the canyon.

The photo shows the last big flood in 1938.

The 6,322-acre Farmington Creek drainage about 55 miles north, on the other hand, is 14 times larger than Lost Creek drainage and has a soil and plant mantle that has regulated streamflow and limited soil erosion and sediment throughout the ages as indicated by the absence of an alluvial fan at the canyon mouth. The race track in the foreground is on the silts and clays deposited in ancient Lake Bonneville about 20,000 years ago.

SETTLEMENTS ON MOUNTAIN STREAMS

When white man first entered the Intermountain area, settlements were made on — indeed limited to — those areas where streams from the humid mountains provided water to irrigate the parched but fertile soil. Some of these early locations are yet only farms or hamlets but others have grown into thriving metropolitan communities sustained by mountain water.

Man found that the normally low summer flow of the streams did not coincide with his needs for water. Moreover, he found the desert valleys deficient in minerals, timber, forage, and recreational opportunities. So, with consummate skill, he dammed the streams and constructed elaborate diversion works to conserve winter and spring runoff; and with equal efficiency, he took to the hills to dig his mine shafts, to cut his timber, to graze his flocks, and to build spiralling roads to scenic and recreational areas. Man, in this western irrigation civilization of ours has altered the long established physical and biological features of the watershed lands and in so doing has changed streamflow characteristics.

When man attempts to alter nature, it is necessary that he understand the laws of nature with which he is dealing. The failure of past civilizations under irrigation was presumably due to failure of the people to understand their complicated environment, or, if they did understand it, their unwillingness to adapt themselves to it.

Figure 16. — In the Intermountain West, cities and towns have developed at the mouths of canyons. (Salt Lake City, Utah)

WATERSHED MANTLE BREAKDOWN

BALANCE DISTURBED BY MAN

It is evident that man, in his utilization of the watershed resources has, in many places, disturbed the balance that has kept the soil in place and runoff under normal limits of control, and has thereby greatly speeded up erosion and overland flow of water from precipitation. Man, in fact, has become a potent geologic agent.

We are now witnessing in many parts of the Intermountain West, a new epicycle of erosion — an erosional event superimposed on the normal geologic cycle. A significant thing about this new epicycle is that accelerated erosion and changed stream regimen are taking place in different topographic and climatic areas. This accelerated soil erosion, and abnormal stream discharges are not occurring everywhere, but are confined almost wholly to those areas where man has altered the natural plant cover. This new erosion event, in other words, constitutes a marked change from the geologic norm of runoff and sedimentation of the immediate geologic past.

The new epicycle of erosion has become manifest in many ways. Recent sedimentation rates and the character of the material deposited are often radically different from the geologic normal. The magnitude of flood discharges has increased and the recessional stages of flow have decreased. Signs of this epicycle are also discernible on the land, for the history of past erosion of a watershed is written not only in the channels and deposits made by streams, but also in the profile of the slopes and in the soil body.

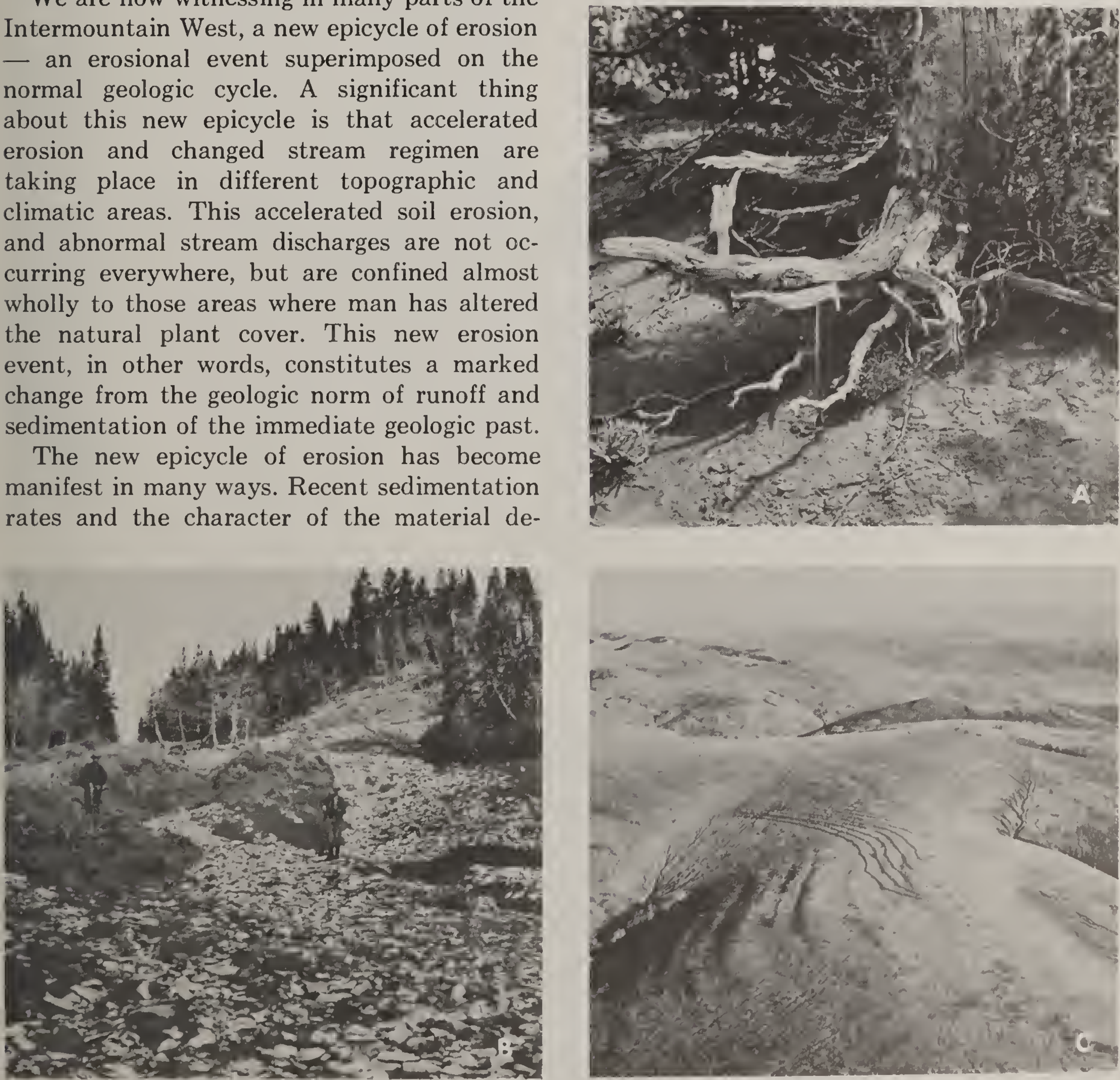


Figure 17. — Erosion has exposed roots of long-established plants and has cut deep gullies into watershed soil: A, Big Game Ridge, Wyoming; B, LaSal Mountains, Utah; and C, Pahvant Mountains, Utah.

EROSION OF WATERSHED SOIL

Watershed soil that has been ages in forming and which has been stable for centuries is now being removed at a rapid rate. Fresh gullies, sharply incised through black soil, exposing the roots of long established plants, are clear-cut evidence of the newness of this process, especially when undisturbed but otherwise comparable sites are not gullied. Similarly, the presence of plants and rocks on pedestals of soil, a gravel pavement, and accumulations of freshly washed soil, gravel, and debris in depressions also constitute valid evidence of accelerated runoff and erosion. These signs are to be found in many parts of the Intermountain West.

EROSION OF STREAM CHANNELS

There is much evidence of greatly accelerated channel cutting in many areas of the Intermountain West. In Utah, for example, at numerous places around the shoreline of the ancient Lake Bonneville, deltas formed at mouths of canyons have been cut by floods of historic times to depths that are as deep as or deeper than all of the cutting that had previously occurred since the lake waters receded from the deltas many thousands of years ago. Here again, this recent channeling has been selective, having occurred only at the mouths of drainage basins in which the plant and soil cover in the headwater areas had been damaged by overgrazing by livestock and man-set fires.

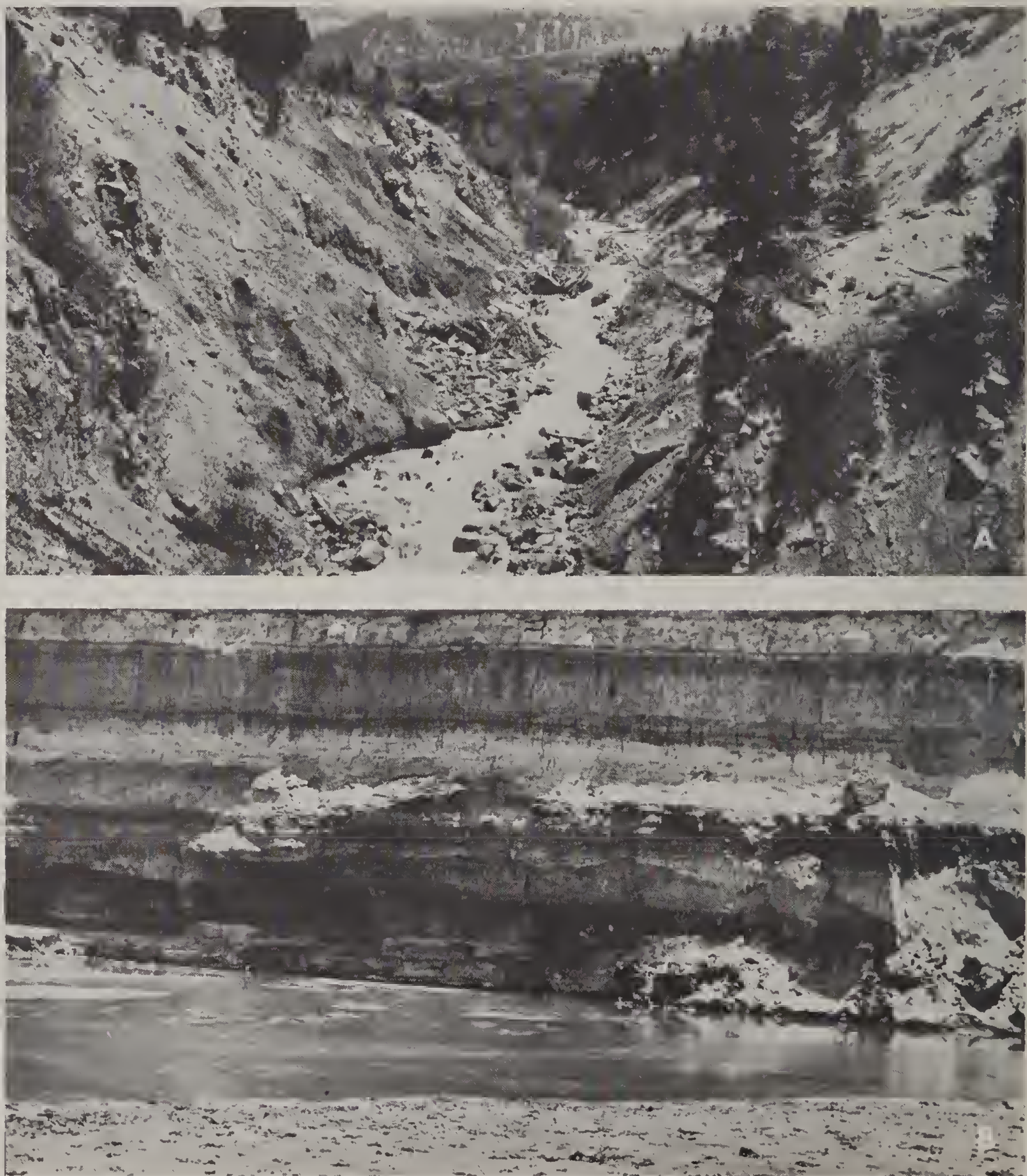


Figure 18. Deep channels have been cut into long-stable, stream courses and valley fill. (A, Ephraim Creek Utah; B, Kanab Creek, Utah)

Figure 19. — Channel cut by runoff from 1.23 inches of torrential rainfall, 1936. (Davis County Experimental Watershed, Utah)

Prior to settlement, and extending back over long periods of time, many valley tributaries to the Colorado River were aggrading — being slowly filled with alluvium. In the last 100 years the processes of aggradation in these valleys has been reversed and the removal of these materials by channeling is occurring extensively. Possible causes of the present channeling of the previously stable valley fill, such as change in the climate, tilting of the earth's surface, and changes in kind and density of plant cover were considered. The only known change capable of reversing the geologic processes was found to be depletion and modification of the plant cover on the watershed lands by overgrazing and the invasion of the valley courses by roads and trails. Naturally barren drainage basins like Bryce Canyon are continuing to flood, to erode, and to yield sediments at the old normal rate.

RAINSTORM FLOODS

Many rainstorm floods are by-products of watershed mantle breakdown. Often, these floods are highly laden with rock, soil, and other debris and are commonly called "mud-rock flows." Serious damage to cities, towns, and farms, and some loss of life, have been caused by them during the past 50 years. Mud-rock floods are associated with torrential summer rains on plant-depleted and gullied watershed lands. They should not be confused with the normal high spring runoff from melting of the snowpack with which the term "flood" is sometimes associated.

Figure 20. — Rainstorm floods have ripped through 150-year-old timber stands as a result of Watershed mantle breakdown. (Teton Mountains, Wyoming)

Table 2.—Summary of some serious summer rainstorm floods in Utah, Idaho, and Nevada

Watershed	Flood Dates	Area — Acres Total	Area — Acres Flood Source	Damage Per Acre Watershed	Damage Per Flood Source Acre	Damage Total
Willard	1923-1936	3,046	1,430	$ 65	$ 139	$200,000
Farmington	1923-1930	6,322	715	36	316	226,235
Steed	1923-1930	1,767	175	46	459	80,463
Ford	1923-1930	1,507	125	185	2,227	278,422
Davis	1930	1,005	75	118	1,582	118,682
Barnard	1930	889	50	15	265	13,290
Parrish	1930	1,378	175	244	1,922	336,497
Perry & vic. (SLC)	8/19/45	1,008	613	344	566	347,000
Pleasant Creek	7/24/46	11,360	1,682	9	63	106,199
Boise Front	8/20/59	5,000	5,000	120	120	600,000
Galena Creek, Nev.	1952-1956	70,000	3,000	0.71	17	50,000

SEDIMENTATION

Sedimentation of stream courses and storage reservoirs constitutes the greatest single threat to the West's water supply. This statement is given great credence by the fact that the soil perched perilously on watersheds above storage reservoirs is enough to fill from several to a thousand times those that now exist and others that are planned for the future. Modern archeologists have uncovered ancient cities in Asia and the Near East that had been buried in sediments which, according to historians, were eroded from timber-covered watersheds whose soils had been exposed by deforestation and over-grazing.

THE NATIONAL SEDIMENTATION PICTURE

Before discussing sedimentation problems in the Intermountain West, a few quotations on the national reservoir sedimentation problem are of great interest.

In November 1941 the National reservoir inventory of the Soil Conservation Service contained records of about 8,900 dams

Figure 21. — Debris catchment basin above reservoir near Santa Barbara, California.

and reservoirs, exclusive of more than 3,800 listed farm ponds, conservation ponds, and low power dams. It is estimated that more than $4,450,000,000 has been invested in these water-utilization developments, including those under construction during 1941. This vast sum represents, for the most part, only the cost of the dams and reservoirs. Except for power plants built into the dams, it does not include dependent developments, such as water-filtration plants, irrigation canals, and power transmission lines . . .

Among the more important problems in the development and maintenance of impounding reservoirs is the loss of storage capacity by silting . . . Reservoir silting is today a serious problem, not just because sediment is deposited, but because it is deposited in such quantities as to cause serious economic and social losses to this generation and the next. The primary cause of this condition is accelerated soil erosion . . .

A study of the effects of silting on the output of power reservoirs in the South Atlantic and Eastern Gulf drainage basins of North Carolina, South Carolina, Georgia, and Alabama during the drought year 1941 revealed a net loss of about 90,000,000 kilowatt-hours as a result of depleted storage capacities. At the cheapest rates for secondary power, this amount of electricity has a value of more than $250,000.

On the basis of these and a few other economic studies, it seems apparent that the average annual damage to all reservoirs in the United States is not less than $10,000,000. Damage may be several times this amount, perhaps as high as $50,000,000 annually. (Brown 1944)

POTENTIAL SEDIMENTATION

Development over the ages of extremely high potential for sediment production may be illustrated by a hypothetical example. At a time in the remote past when the land surface was largely bare rock and without a plant-protected soil, torrential rains washed the weathered material into the valley about as fast as it was produced. Then, as plants developed — lichens, mosses, and finally seed plants — the rock fragments were held in place by them and a soil mantle gradually developed. Over the ages, as the soil and plant mantle accumulated, often to a depth of 2 to 4 feet, the sedimentation rate of course decreased accordingly — possibly to as low as 0.0025 acre-feet per square mile per year — to use an actual measured example. This low rate of sediment production existed for thousands of years as the soil mantle got deeper and deeper, which of course, increased the amount of potential sediment on the watershed from practically nothing (bare rock condition) to thousands of acre-feet (deep soil).

This long-stable soil mantle is perched like the proverbial "sword" ready to be released if the grasses, shrubs, and trees that bind the soil in place are damaged or destroyed by excessive use, fire, or other causes. Based on actual measurements, sediment production may be increased from 1,000 to 6,000 times by improper land use.

Figure 22. Soil held in place on these steep slopes could, if released, fill this reservoir (Pine View Reservoir, Utah)

An example of high sedimentation potential damage is provided by the relationship of the 200,000-acre Ogden River Watershed to the Pine View Reservoir with a storage capacity of 110,000 acre-feet. Only a few inches of soil eroded from the watershed and transported to the reservoir would be enough to replace much of the storage capacity.

The tremendous speed at which long-stable soils and valley sediments were washed away in certain valleys of the Colorado River drainage is described as follows:

> *... the amount of fill removed in a typical one-mile stretch is estimated as one million cubic yards for Grand Gulch, 800,000 cubic yards for Cottonwood Canyon, and 650,000 for Butler Wash. North of Wilson Mesa, a canyon 6 miles long, 160 to 200 feet wide, and once filled to a depth of nearly 80 feet, has been entirely stripped of alluvium.*
>
> *It seems reasonable to assume that the time consumed in tearing down and transporting such great quantities of sand, gravel, and silt from hundreds of canyon floors would be measured at least by centuries, but nearly all the terraces have been formed during the last 50 years, many during the last 10 years, and each year adds to their number. (Gregory 1938)*

SEDIMENT IN UPLAND STREAMS

Sediment that comes from sheet and gully erosion on mountain watershed lands does damage to the headwater streams above the valley bottoms in a variety of ways. Damage to the fishing resources can be serious as observed in the Snake and Salmon River drainages of Idaho, where salmon spawning beds have been damaged or destroyed by sediments. Following a recent rainstorm flood heavily laden with sediment in the Upper Salmon River, fisheries experts estimated the value of river-bottom salmon spawning beds, damaged by sediment, as high as $80,000 per acre per year. Duration of the damaged conditions will depend on the amount and character of undesirable sediments deposited and the time required for them to be washed out of the spawning beds. This may vary from a few to many years. Sediment damages pools, meanders, and riffle sections of streams that provide the important spawning and feeding areas. Sport fishing on National Forest lands in the Intermountain Region alone in 1962 put an estimated 14 million dollars in circulation by 1.9 million fishermen.

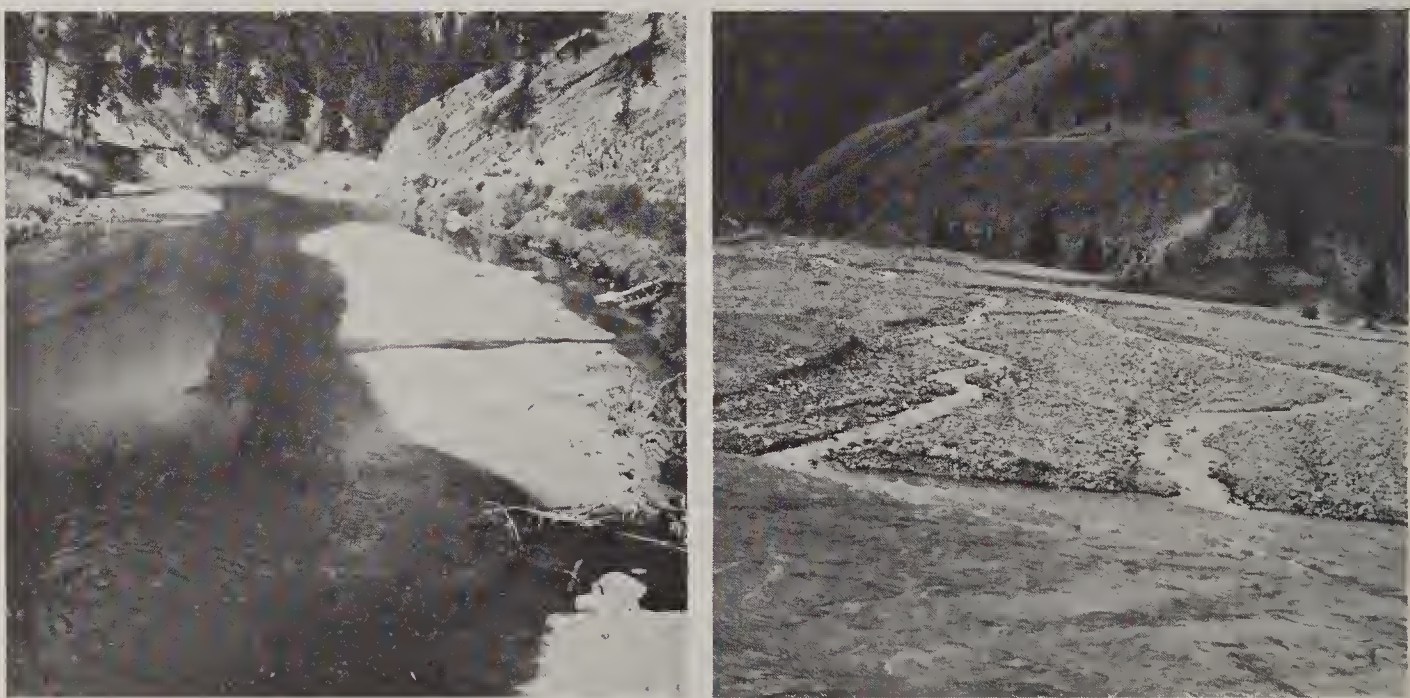


Figure 23. — Many upland streams are choked with sediment from eroded watershed soil. (Salmon River, Idaho)

Silt in upland streams can do great damage in many other ways. For example, there is a large number of small to medium hydro-electric plants on or near National Forest lands in the Intermountain Region, all subject to various degrees of damage by silt and sediment floods. Then, too, sediments are a threat by pollution and physical damage to irrigation systems, to domestic water supplies, and to cities and towns.

Figure 24. — Silt dredged from canal. (Horseshoe Bend, Idaho)

DAVIS COUNTY FLOOD SEDIMENTS

Sediments produced by the Davis County, Utah floods of 1912, 1923, and 1930 were without precedent in modern times. A report of extensive studies of the 1923 and 1930 floods stated that:

> *It is concluded upon the foregoing geologic evidence that the 1923 and 1930 floods marked a radical departure from the normal post-Bonneville erosion and sedimentation in the canyons of Farmington-Centerville District. In depth of cutting, quantity of material, and in size of boulders carried, these floods exceed any others that have taken place in this locality since the recession of Lake Bonneville. The alluvial deposits made since the time of Lake Bonneville (about 20,000 years) are small, and the quantity of material brought from the canyons and added to them by the recent floods is all out of proportion to the amount brought down through the previous thousands of years of Lake Bonneville history. (Bailey, Forsling, and Becraft 1935)*

This conclusion is vividly illustrated by the accompanying photographs: one showing the fine sediments of the Lake Bonneville period; the other a 200-ton boulder from the 1930 mud-rock flood.

It is interesting indeed, that measurements of sediment from the seriously overgrazed Parrish Creek, Utah, watershed for the 17 years immediately following the 1930 flood averaged 6.25 acre-feet per year for each square mile of watershed. This sediment rate is about 2500 times greater than the 0.0025 acre-feet per square mile per year for the near pristine Morris Creek watershed, nearby, during the same period.

Figure 25. — In size and quantity, historic stream sediments (above) greatly exceed those of the geologic past (below). (Centerville, Utah)

SEVIER RIVER SEDIMENTS

Sedimentation in some of the channels and reservoirs in the Sevier River Basin, Utah, is particularly serious. The Sevier Bridge Reservoir had, according to a survey by the State of Utah, an original capacity of about 250,000 acre-feet when completed in 1912. A 1940 survey by the Soil Conservation Service shows a loss of about 16,000 acre-feet in 28 years. This represents a storage capacity loss each year of water sufficient to irrigate a 250-acre farm.

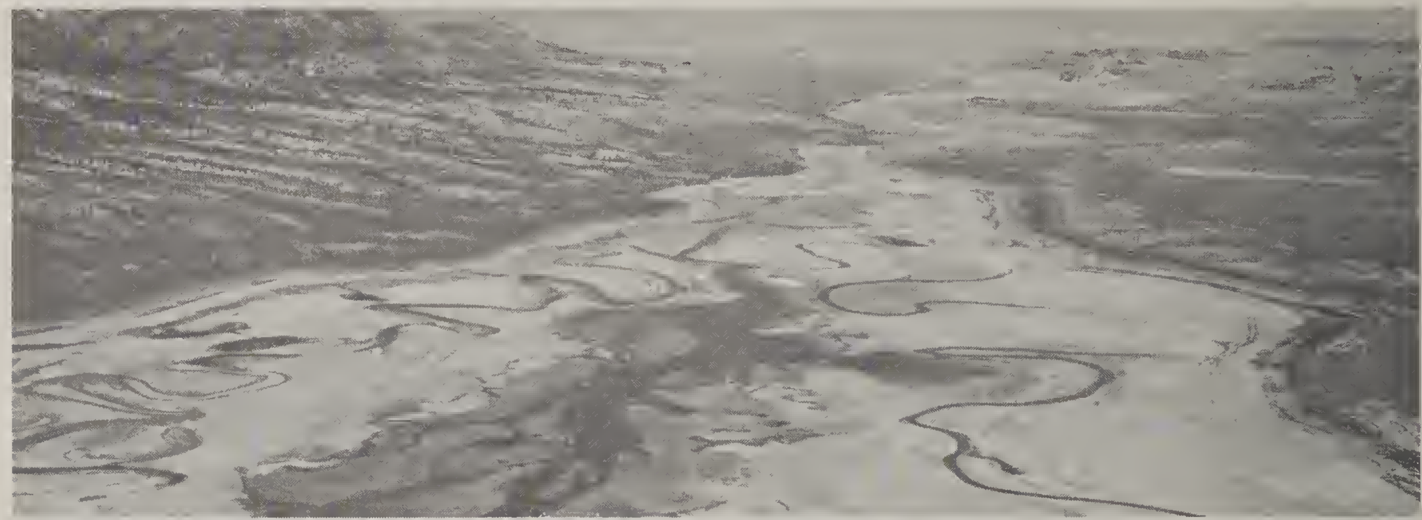


Figure 26. — Sediment in the Sevier Bridge Reservoir near Fayette, Utah (above) and in the Otter Creek reservoir near Antimony, Utah (below).

Sediment in the Sevier River 10 miles above the reservoir near the town of Redmond, became such a serious problem that the U. S. Corps of Engineers dredged the channel and installed facilities to keep it clear of sediment. This cost about 1⅓ million dollars. The work seems to be protecting the Redmond area from silt damage by flushing sediment downstream — to the reservoir. However, sediment problems are usually not solved by shifting the deposits from one place to another. The problem must be attacked at its source — on the watershed lands and in the high valleys where surface runoff and soil erosion originate which result in downstream sedimentation. Correcting this problem is largely a job of land management on the watershed.

LAKE MEAD SEDIMENTS

The Colorado River Basin has been recognized for a long time as a naturally heavy producer of sediment. Authorities who have made careful study of watershed conditions, however, contend that a large amount of the sediment now carried by the river is the result of accelerated erosion.

The sedimentation threat to Lake Mead

was described by an eminent engineer as follows:

> *The construction of large storage reservoirs on some of the silt-laden streams of the West has focused attention on the part sedimentation will play in the future history of Western civilization. . . .*
>
> *The Boulder Dam in the Colorado River will create the largest storage reservoir in the world. Upon it will depend not only the security of the entire Imperial Valley against damages from floods, and the irrigation of millions of acres of land, but also the domestic and irrigation supply for the metropolitan district of Southern California. The ability to furnish power to the people in seven States also hinges upon its functioning. Unless remedial measures are adopted, this reservoir will become virtually useless, by reason of silt deposits, before the passing of the fifth generation. (J. C. Stevens 1936)*

Capacity of Lake Mead originally was about 32,000,000 acre-feet, but sedimentation is reported to be in excess of 100,000 acre-feet a year — 1,000,000 acre-feet in 10 years.

In the long run the multi-billion dollar cost of the huge Colorado River Storage Project will be trivial compared to the economic and social distress that could occur if water storage, flood control, and power generation are seriously impaired.

ELEPHANT BUTTE SEDIMENTS

Elephant Butte reservoir on the Rio Grande, about 125 miles below Albuquerque, also provides an object lesson in the consequences of sedimentation. The dam was completed in 1915 to store about 2.6 million acre-feet of water. By 1947 about 437,000 acre-feet of sediment (17% of total capacity) had been deposited above the dam. In addition to this

Figure 27. — Sediment in San Juan River near Bluff, Utah.

storage loss, it is estimated that about 300,000 acre-feet of water is lost annually to plants (phreatophytes) that have invaded the newly deposited sediments in the river bed above the dam.

The Commissioner of Reclamation, at a meeting in Albuquerque about 15 years ago, expressed the shocking truth this way:

> *Gentlemen, because of your dire need, I have decided to approve and support the plan and expenditure of approximately one-hundred million dollars, but I want to warn you that for this \$100,000,000 we are buying approximately 50 years of time unless the destructive land uses of the Rio Grande watershed are changed and improved. Unless your land uses are drastically improved at the end of such period your reservoirs will be filled with silt and the valley will be again choked with the deposits washed from the uplands into the valley. (Shephard 1945)*

Although the proposed expenditure was not made, the problem has been attacked recently by construction of river channels to by-pass the sediment beds and by eradication of useless water-consuming plants. Then too, it is reported that study of the big program of structural measures for sediment control referred to above has been reactivated. In connection with this, a sharp look is being taken also at the land use problem referred to by Commissioner Straus.

ECHOES FROM THE PAST

Peoples of past civilizations have experienced problems that grew out of damage to watershed vegetation, soil erosion, and sedimentation. Discerning men who have witnessed the effects of watershed breakdown have left statements that eloquently describe conditions and consequences.

North Africa

Many shepherds have destroyed my vinyard; they have trampled down my portion; they have made my pleasant lot a desolate waste. They have made it a desolation; in its desolation it mourns me; the whole land is made desolate because no man layeth it to heart. (Jeremiah 12: 10-11 Am. Trans. 600 B. C.)

Greece

There are mountains in Attica which can now keep nothing but bees, but which were clothed, not so very long ago, with fine trees producing timber suitable for roofing the largest buildings, and roofs hewn from this timber are still in existence. There were also many lofty cultivated trees, while the country produced boundless pasture for cattle.

The annual supply of rainfall was not lost, as it is at present, through being allowed to flow over a denuded surface to the sea, but was received by the country, in all its abundance — stored in pervious potter's earth — and so was able to discharge the drainage of the heights into the hallows in the form of springs and rivers with an abundant volume and wide territorial distribution. The shrines that survive to the present day on the sites of extinct water supplies are evidence for the correctness ofmy present hypotheses. (Criteas of Plato, 427-347 B.C.)

The Mediterranean Basin

Man is constantly modifying the earth and making it more and more uninhabitable . . . The Roman Empire, at the period of its greatest expansion, comprised the regions of the earth most distinguished by a happy combination of physical conditions, . . . in climate, in fertility of soil, in variety of vegetable and mineral products . . . advantages which have not been possessed in an equal degree by any territory of like extent in the Old World or the New . . . Today we find that more than one half of their whole extent is either deserted by civilized man and surrendered to hopeless desolation or at least greatly reduced in both productiveness and population . . . vast forests have disappeared, soils of the alpine pastures . . . are washed away; meadows once fertilized by irrigation are waste and unproductive . . . (Marsh, 1861, The Earth as Modified by Human Action)

HOW WATERSHEDS FUNCTION

In this section we shall consider briefly how watersheds convert the rain and snow they receive to streamflow and ground water, and the relation of soil and vegetation to the processes involved. Professor Thomas C. Chamberlain, eminent geologist of the University of Chicago, addressed the "Governors' Conference" of 1908, called by President Theodore Roosevelt, to consider the Nation's forest and water resources. He pointed out the interrelatedness of plants, soil, and water, a concept that has been proved fundamental by subsequent experience and research, in the following words:

> *Soil production is very slow. I should be unwilling to name a mean rate of soil formation greater than one foot in 10,000 years. In the Orient there are large tracts almost absolutely bare of soil on which stand ruins implying former flourishing populations . . . It must be noted that more than a loss of soil fertility is here menaced. It is loss of the soilbody itself, a loss almost beyond repair. When our soils are gone we too must go unless we find some way to feed on raw rock or its equivalent . . . The key lies in the control of the water which falls on each acre . . . This gives a minimum of wash to foul the streams, to spread over the bottom lands, to choke up the reservoirs, to waste water power, and to bar up the navigable rivers . . .*

WATERSHED RESEARCH

The development of the National Forest system did more for conservation than to initiate management of the National Forest lands. It led also to a program of scientific research into the facts and principles essential for improving management, not just for National Forest lands, but for forest and range lands in all ownerships.

Early forest administrators, faced with problems of handling land areas of great physical and biological complexity, sensed the need for research help, and a branch of research was organized in the Forest Service and scientists were put to work to provide answers. Contributions of wildland research to conservation have filled many books and have reached into every phase of wildland management.

Figure 28. — Many kinds of data must be obtained in conducting watershed research.

Management of wildlands for water control is largely the management of uses of the lands — grazing, timber harvesting, road building, mining, and recreation. Therefore, knowledge of all phases of use is essential to an understanding of how watersheds function.

We have now gotten more knowledge of our forest resources, of forest growth and drain, as surveys have gone forward and new and more efficient survey methods have been developed. Research has determined silvicultural requirements and cutting practices of a number of forest types, to insure maximum sustained production. It has tackled the problem of getting natural regeneration in forests, of artificial planting in cut-over areas and burns that are now brushfields, and, on the other hand, of stepping up production in crowded, stagnated stands. It has contributed to a knowledge of fire detection, behavior, and control, and has developed methods of coping with certain forest insects and diseases.

Figure 29. — Civilian Conservation Corps pioneering the construction of experimental contour-trenches, 1936. (Davis County Experimental Watershed, Utah)

Research has also developed and tested methods of stabilizing gullied watershed soil that has been damaged by rainstorm runoff. Contour-trenches, used today in the Intermountain West and some foreign countries, are the result of about 30 years of research and development by the Intermountain Forest and Range Experiment Station and National Forest Administration. The first contour-trenches were constructed in 1933 using horse-drawn plows, tractors with bulldozers, and hand labor on slopes up to 35 percent. Now all work is done by heavy machinery on slopes up to 70 percent.

Range research has tested methods of grazing management to improve forage and to check erosion where native plant cover has been damaged by overuse. It has brought to light facts about the forage requirements of wildlife from which we hope to strike a proper balance between wildlife and livestock use. It has developed criteria by which the land manager "reads the range," evaluates its condition and learns whether it is getting better or worse. It has developed methods of getting rid of undesirable species and methods of artificial seeding; and it has introduced and tested new plants that have proven their value or that hold great promise for conservation, both as forage and for controlling erosion.

Figure 30. — Experimental contour-trenches built in 1935 were damaged by melted snow runoff (left); ten years later after repair and seeding (right). (Davis County Experimental Watershed, Utah)

The fact may seem strange to us now that the watershed value of forests was a subject of very live controversy 50 years ago. Watershed research has established many of the relations between vegetation, erosion and streamflow, not only for timberland, but for brushland and grassland as well. This research has demonstrated that all vegetation, even lowgrowing herbaceous plants, plays an important role in the reception and disposition of water on each part of the earth's surface on which it grows. It has demonstrated that relations exist between the uses made of wildlands and their ability to control water and erosion, and it has made a start in establishing cover requirements of safe use.

DEVELOPMENT OF CONCEPTS

But going beyond any single field, research has made its greatest contributions in the development of basic concepts. These include a growing understanding of the interrelatedness of plants, animals, soils, and water; a growing appreciation of the functioning of each tract of wildland, be it covered with trees, sagebrush, or grass, in its disposal of rain and snow, in its production of grass or timber, and in its protection of soil. Such understanding forms the solid foundation of true conservation.

HISTORY OF WATER RESEARCH IN THE INTERMOUNTAIN WEST

The first formal watershed research in the Intermountain West began with the establishment in 1912 of the Great Basin Experimental Area near Ephraim, Utah. The first study was concerned with the relation of vegetation to surface runoff and soil erosion. The now famous 10-acre watersheds A and B, established at that time, are believed to have longer continuous measurements of runoff and soil erosion in relation to plant cover than any other watersheds in the world.

In response to a great need for knowledge in all phases of wildland management, Congress, in 1927, passed the McSweeny-McNary Law authorizing the establishment of forest and range experiment stations in 10 National Forest Regions and in Puerto Rico. The Intermountain Forest and Range Experiment Station was established, with headquarters at Ogden, Utah, and research on all phases of forest and range problems was authorized, including watershed research. The watershed investigations that had been underway since 1912 at the Great Basin Experimental Area were expanded in scope and intensity to include different conditions in all parts of the new station territory, comprising Utah, Ne-

vada, southern Idaho, and western Wyoming. In 1953, northern Idaho and Montana were placed under the Intermountain Forest and Range Experiment Station and watershed investigations were continued and enlarged in these states.

RESULTS OF RESEARCH

In the field of watershed management research, experiments have been carried on during the past 50 years to determine how the water from rain and snow is disposed of on watershed slopes. This has involved the following determinations:

- Precipitation—its character and amount.
- The origin of streamflow.
- Loss of water by interception of precipitation by vegetation.
- Over-surface runoff.
- Infiltration and percolation of rainfall and snowmelt.
- Relation of vegetation and litter cover to runoff from watershed slopes, soil erosion, and floods.
- Consumption of water by vegetation.

These studies have been carried on using small plots up to 1/10 acre in size, and complete watersheds varying in size from 10 acres to several hundred acres. Results have been reported in more than 100 publications but only the highlights of the most significant experiments can be reported here.

RUNOFF EXPERIMENTS ON PLOTS

Parrish Creek surface runoff plots — Sixteen plots to measure surface runoff and erosion were constructed in 1934 at the head of Parrish Creek, elevation 8,200 ft., on the Davis County Experimental Watershed, to check the conclusion reached by the Dern Flood Commission in 1930, that the floods were due primarily to reduction in vegetation on the watershed slopes. This group of experimental plots consisted of six 1/40-acre plots on flood-source land with sparse annual weed cover, six 1/40-acre plots with depleted brush cover, and four 1/10-acre plots with cover of aspen trees and herbaceous plants from which no flood water came. All are equipped to measure precipitation, surface runoff, and soil eroded.

From 1936 to 1946, the plots had complete protection from grazing. Precipitation, surface runoff, and soil eroded were carefully measured. Here the results are summarized: (1) The 1/40-acre flood-source area plots with only a 10% cover of the small annual weeds (kitchen weed) allowed about 20% of rainfall to discharge as surface runoff from storms with a maximum intensity of only 1.5 inches per hour for 5 minutes. Over-surface discharge increased up to about 60% of rainfall when intensity reached 6.0 inches per hour. Soil loss varied from 8 cu. ft. to 33 cu. ft. per acre. Total rainfall in individual storms varied from 0.5 inch to 1.14 inches during a 15 to 30 minute period. (2) Surface runoff, on the other hand, from the 1/10-acre nonflood source plots, which received the same storms, was practically nothing — about 0.5 of one percent of precipitation, and no soil was eroded.

These results confirmed the conclusions reached by the Dern Flood Commission investigators, that destruction of vegetation on parts of the upper watersheds of Farmington, Steed, Davis, Ford, Barnard, and Parrish Creeks was the principal cause of the devastating floods form 1923 to 1930.

Figure 31. — Parrish runoff plot No. 7 before and after treatment. (Davis County Experimental Watershed, Utah)

Beginning in 1947, the vegetation on two of the 1/10-acre nonflood-source Parrish plots was changed. All plants and litter were removed from Plot No. 7, and aspen trees were removed from Plot No. 8, leaving the herbaceous understory of grasses, forbs, and shrubs. Plot No. 9 was left in its well-vegetated condition. During the 3-year period 1947 to 1949, precipitation, water uses and losses, and soil eroded were measured. Results are summarized in Table 3.

Table 3.—Average annual precipitation, water Losses, and Amounts of Water Available for streamflow on three Aspen sites, 1947-49

	Cover Conditions		
	Bare (Plot 7)	Herbaceous (Plot 8)	Aspen (Plot 9)
Precipitation (inches)			
Winter (October-May)	45.43	45.43	45.43
Summer (June-September)	7.34	7.34	7.34
Total	52.77	52.77	52.77
Water losses and uses (inches)			
Snow evaporation	3.00	2.75	2.50
Rainfall interception	0.00	0.77	1.16
Winter transpiration	0.00	0.00	1.00 1/
Summer evapo-transpiration	11.21	14.83	17.70
Total	14.21	18.35	22.36
Water available for streamflow (inches)			
Overland flow	0.40	0.02	0.01
Seepage flow	38.16	34.40	30.40
Total	38.56	34.42	30.41
Soil loss (tons per acre)			
Three-year total, 1947-49	18.66	0.00	0.00
Average annual	6.22	0.00	0.00
July 10, 1950 storm (0.70 inch)	13.50	0.00	0.00

1/ Estimated

Practically no overland flow occurred from the herbaceous Plot No. 8 and aspen Plot No. 9 — only 0.02 inch and 0.01 inch respectively. This amounts to only 0.038 and 0.019 of one percent respectively of the 52.77 inches of annual precipitation. Bare Plot No. 7, on the other hand, produced 0.40 inch of runoff or 0.76 of one percent of total annual precipitation. This, however, is 40 times as great as runoff from the aspen plot and 20 times as great as from the herbaceous plot.

One of the most convincing demonstrations of the effect of vegetation and litter in preventing soil erosion and surface runoff from summer rainstorms, is provided by the 22-year record of Plot No. 7. During the first period, from 1936 to 1946, when the plot had aspen-herbaceous cover, 130 summer rainstorms produced 34.08 inches of water. Of these, 23 storms caused minute amounts of runoff for a total of 24.3 cu. ft. (0.07 area inch). Then, all vegetation and litter were removed and measurements of runoff and sediment made for another 11-year period. Results are shown in Table 4.

Table 4.—Overland flow and soil erosion before and after denudation of Parrish Plot No. 7

Period	Summer storms Number	Ppt. depth Inches	Overland flow Storms Number	Overland flow Amount Cu. ft.	Sediment eroded Storms Number	Sediment eroded Rate Cu. ft.	Sediment eroded Depth Inches
Before denudation (1936-46)	130	34.08	23	23.3 (.07 in.)	0	0	0
After denudation (1947-57)	161	42.23	49	1655.5 (4.6 in.)	34	242.7	0.67

During the second 11-year period from 1947 to 1957, while the plot was bare, 161 storms produced 42.23 inches of rainfall. Of these, 49 storms produced 4.6 inches of runoff (1655.5 cu. ft.) or 68 times as much as in the previous 11-year period.

The soil erosion record is even more striking. Under natural aspen cover, no soil was eroded, but during the 11-year bare period, 34 of the 161 rainstorms eroded 242.7 cubic feet of soil per plot, equal to 0.67 inch deep over the entire plot.

Farmington Infiltration and Seepage Plots — To understand more fully the disposition of water from rain and snowmelt by the plant and soil mantle, especially designed plots were constructed in Farmington Canyon on the Davis County Experimental Watershed at 7,000 feet elevation, and at the Great Basin Experimental Area at 10,000 feet elevation near the head of Ephraim Creek. Concrete-lined pits 8 feet deep were installed with facilities for collecting yearlong soil moisture samples at 1-foot intervals from 1 to 6 feet deep. As the snow melted, infiltration of water into the soil, changes in soil moisture and percolation of free water through the soil, were observed and measured. Other data collected at the plots included individual rain and snow storms yearlong, accumulation and melting of the snowpack, and snowmelting rates. Streamflow from the watershed in which the plots were located was measured yearlong.

Plots at both locations told essentially the same story about infiltration, waterholding capacity of the soils and percolation. Therefore, only the results on a north-facing plot in Farmington Canyon are reported here.

The following discussion explains the rela-

Figure 32. — Taking samples from soil moisture study pit. (Great Basin Experimental Area, Utah)

tion between precipitation, water stored in snow, soil moisture, and streamflow, which is shown in figure 33.

A. **Precipitation.** Forty-two snow storms from October 10 to May 1 produced 18.7 inches of moisture, about 49% of the total annual precipitation.

B. **Water Stored in Snow.** Snow started to accumulate about October 10, reached a maximum water content of 18 inches by March 20 and had melted by May 25.

C. **Soil Moisture.** This discussion of soil moisture will be confined to the moisture that plants obtain for growth from the soil. This is the difference between the amount of water held in the soil at complete capillary saturation, referred to as "field moisture capacity," and the amount of water in the soil when plants wilt permanently, commonly called the "wilting moisture content." The amount of water measured by difference in these two values is referred to as "available water." Considerable water not available to plants remains in the soil at the wilting moisture content.

By October 1, the 6-foot column of soil held practically no available water, but it increased to 4 inches by October 10 as a result of rains. Soil moisture remained at that level until about March 1. On April 12 the soil contained 14 inches of available water which constituted field moisture capacity as a result of snow melting and storage of water in the soil. Free-water then began percolating through the soil body, giving rise to seepage flow.

Free-water dropped below the 6-foot soil column on June 5 — 57 days after it first appeared at the top of the soil body.

Herbaceous plants began to draw water from the soil about May 15, a process which continued until about September 15, at which time all water available to them — about 14 inches — had been extracted by avaporation and transpiration. Since aspen were in flower several weeks before the snowpack melted, it is assumed they used some water before the soil moisture study got underway. This was estimated at 1.0 inch. In addition to the water stored in the 6-foot soil body, evapo-transpiration consumed 3.7 inches of rain that fell on the plots between June 10 and September 25. At no time during this summer period did rainwater percolate deep enough to reach soil holding free-water and contribute to seepage flow. From these tests and many observations, it seems safe to conclude that summer rain on watershed slopes in the Intermountain Region that allow no surface runoff, seldom contribute directly to streamflow. Under certain conditions, however, when extensive rainfall occurs on saturated or very wet soil, they may contribute substantially to streamflow through infiltration and percolation, as was the case early in June 1944. (See Fig. 33-D.)

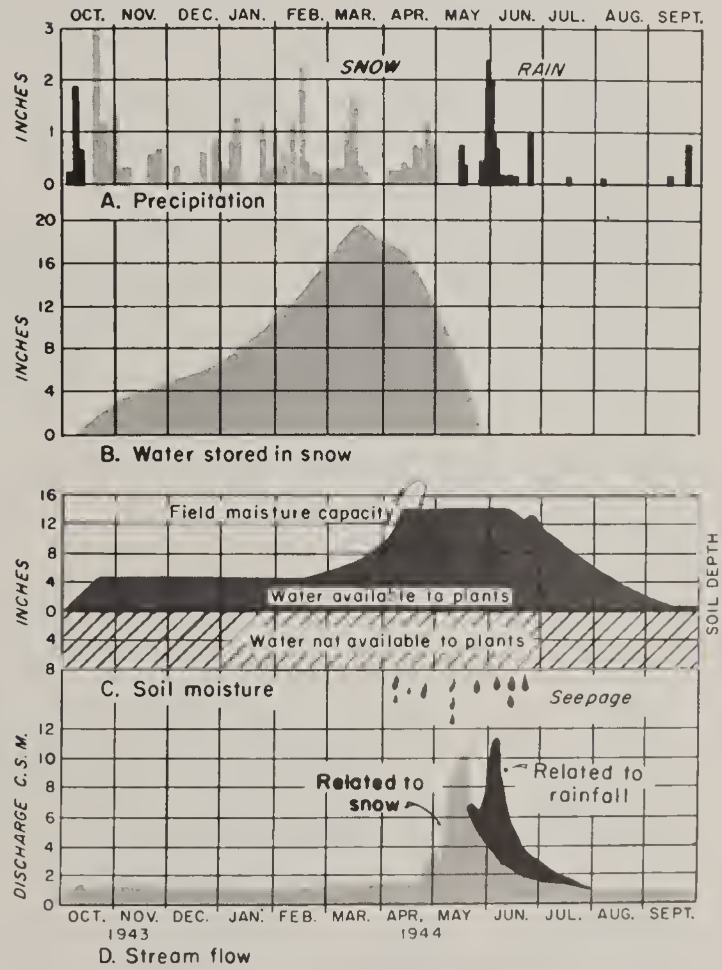


Figure 33. — Farmington filtration and seepage data: A, Annual precipitation as rain and snow; B, Accumulation and melting of the snowpack; C, yearlong changes in soil moisture in a soil body six feet deep; D, flow chart of the related stream. (Davis County Experimental Watershed, Utah)

D. **Streamflow.** The stream discharge from the drainage in which the above plot studies were made remained almost constant from October 1 to April 25 while 18 inches of water accumulated in the snowpack; and almost 6 inches (water equivalent) melted and entered the soil. In addition about 6 inches of water that fell as snow or rain during April entered the soil. Streamflow increased rapidly to a peak about May 15, after the soil became saturated, and free-water began to pass through it. Flow declined rapidly beginning May 15 when the snowpack on about 75% of the watershed had disappeared.

Then, about June 3, flow jumped to the highest peak of the season when heavy rains fell on a nearly saturated soil which allowed much of the water to percolate through the soil to streams rather than being stored in the soil.

Oversurface flow, even in minute amounts, did not occur on the areas adjacent to the soil moisture sampling pits nor from any of the well-vegetated lands on the watershed.

Snowmelting rates — The rate at which snow melts was studied at the Farmington Infiltration plots and at the Great Basin Experimental area. The amount of water melted from the snow was determined on study plots by measuring the depth of snow melted each hour and calculating the water equivalent using snow density. The accompanying chart shows the amount of water melted from the snow for the 24-hour periods May 21, 1942, at Great Basin Experimental Area, elevation 8,700 feet, and on July 29, 1941, at Davis County Watershed, 8,500 feet elevation. At Great Basin, maximum melt for a single day of record was 2.3 inches on May 21, 1942 and highest melt during one hour was 0.34 inch on that day. Average daily melt for the 26-day period from May 5 to June 21 was 0.974 inch water equivalent.

On the Davis County Watershed, near Francis Peak, on July 29, 1941, the 24-hour melt amounted to 3.5 inches water equivalent, and the highest hourly amount was 0.49 inch. During the entire period of observation at Great Basin, no snow ever melted at night (from sundown to sunup). At the Davis County location on the warm night of July 28-29 a very small amount of snow disappeared, but since there was no drainage of water through the snowpack the loss was assumed to be from evaporation.

These very slow melting rates indicate why snowmelt water infiltrates into the soil, even where vegetation is absent. A point of unusual interest is that the highest hourly rainfall rate (8 inches per hour for 5 minutes) recorded on the Davis County experimental area exceeds the highest hourly snow-melting rate, 0.49 inch per hour, by 16 times.

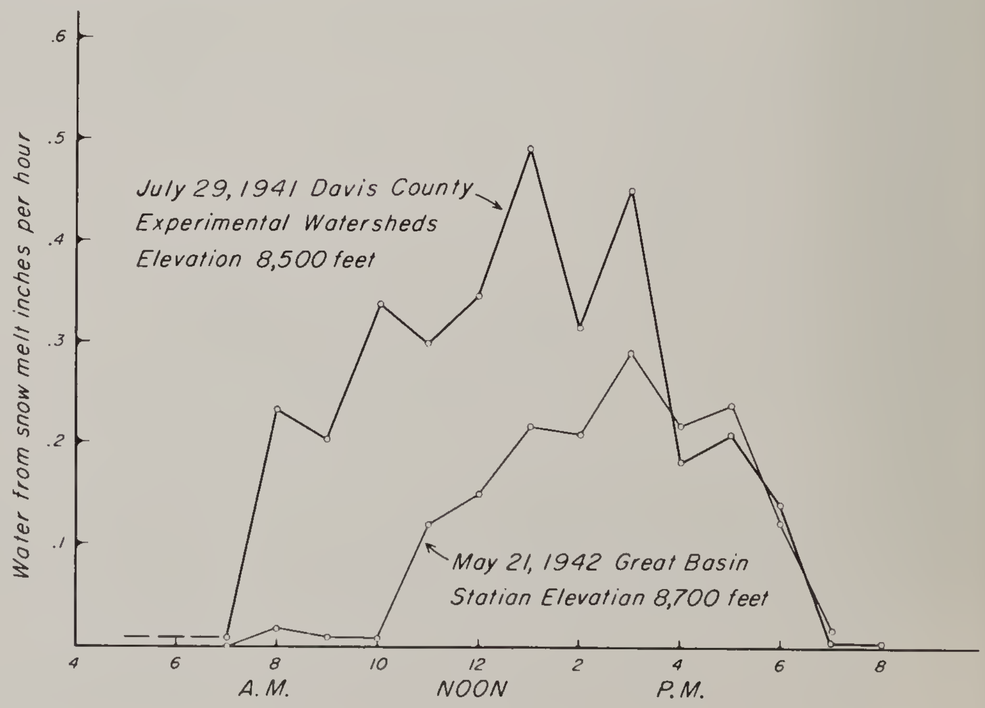


Figure 34.
Hourly snowmelting rates, and the daily melting period, on the Wasatch Plateau and the Wasatch Mountains, Utah.

Runoff Experiments Using Artificial Rainfall — Because flood-producing rainstorms occur at infrequent intervals, artificial rainstorms on small plots have been used for about 30 years in Idaho and Utah to speed up data gathering on the relation of vegetal cover to rainstorm runoff on range lands. In each specific experiment, size of plots, slope of the land, and the amount and intensity of rainfall were constant, but the character and density of plants and litter were varied.

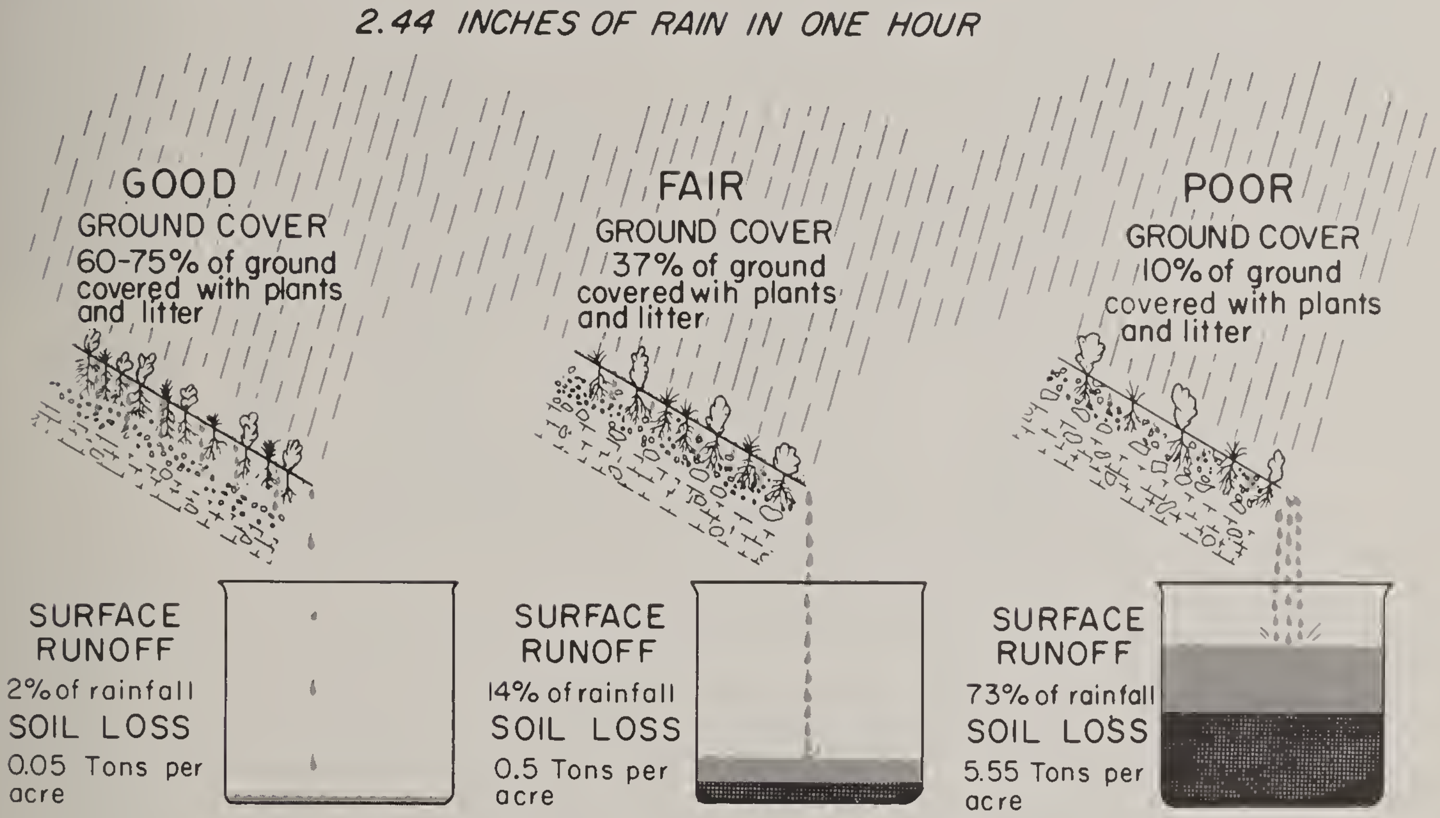


Figure 35. — The effect of watershed condition on rainstorm runoff and erosion (average of three plots for each condition) on subalpine watershed (Great Basin Experimental Area, Utah)

Experiments on the headwaters of Ephraim Creek, Great Basin Experimental Area, are summarized in the accompanying chart-diagram. The chart shows land destruction that can occur from a single rainstorm. With groundcover in the 60 to 75% range, only 2% of rainfall left the plot as surface runoff and soil eroded was only 0.05 tons per acre (0.0005 tons, or one pound, per 1/100-acre plot). With poor groundcover of only 10% vegetation and litter, 73% of the rainfall left the plot and soil eroded was 5.5 tons per acre (0.055 tons per 1/100-acre plot, or 110 pounds).

At the Boise Basin Experimental Forest in southern Idaho, the effect of plant cover conditions on oversurface flow and erosion have been studied on unstable granitic soils by applying artificial rainfall on 6′ x 6′ plots.

Two specific ground cover conditions were shown to be necessary to prevent overland flow and soil erosion from wheatgrass and cheatgrass annual weed range sites. These conditions were: (1) that no less than 70 percent of the soil surface be covered with vegetation or litter, and (2) that bare openings between plants and patches of litter be no larger than 4 inches in diameter on wheatgrass sites and 2 inches on cheatgrass sites.

When these ground cover conditions prevailed, overland flow and soil erosion were effectively controlled during a 30-minute rainstorm occurring at a constant rate of about 3.7 inches per hour applied with a rainfall-simulating infiltrometer.

RUNOFF EXPERIMENTS ON WATERSHEDS

At Davis County and Great Basin, the effects of good and poor vegetal cover in preventing rainstorm floods have been studied on complete watersheds.

Halfway Creek compared to Morris Creek — On the Davis County area, studies were conducted on Halfway Creek drainage, a 464-acre watershed where fire in 1938 destroyed about 50 acres of dense brush vegetation, and on Morris Creek drainage, a 167-acre watershed with an excellent cover of vegetation. A heavy rainstorm on August 10, 1947, common to both watersheds, produced markedly different stream discharges.

The runoff record of Halfway Creek shows the highest stream discharge from the snowpack of 31.39 inches to be 4.6 cubic feet per second on May 8, 1947. Then on August 10, when the stream was flowing only 0.6 cubic foot per second, a 0.79 inch rainstorm occurred with a maximum 5-minute intensity of 4.92 inches per hour. Peak discharge increased over a 15-minute period to an estimated 500 cubic feet per second and carried boulders that weighed more than a ton. The low peak discharge from the snowpack was a result of normal snowmelting (about 0.5 to 2.0 inches of water per day), infiltration into the soil, and percolation to the stream. The big flood on August 10, on the other hand, was the result of the torrential rain on 50 acres of relatively bare soil which resulted in oversurface flow to the channel of about 50 to 60 percent of the rain that fell.

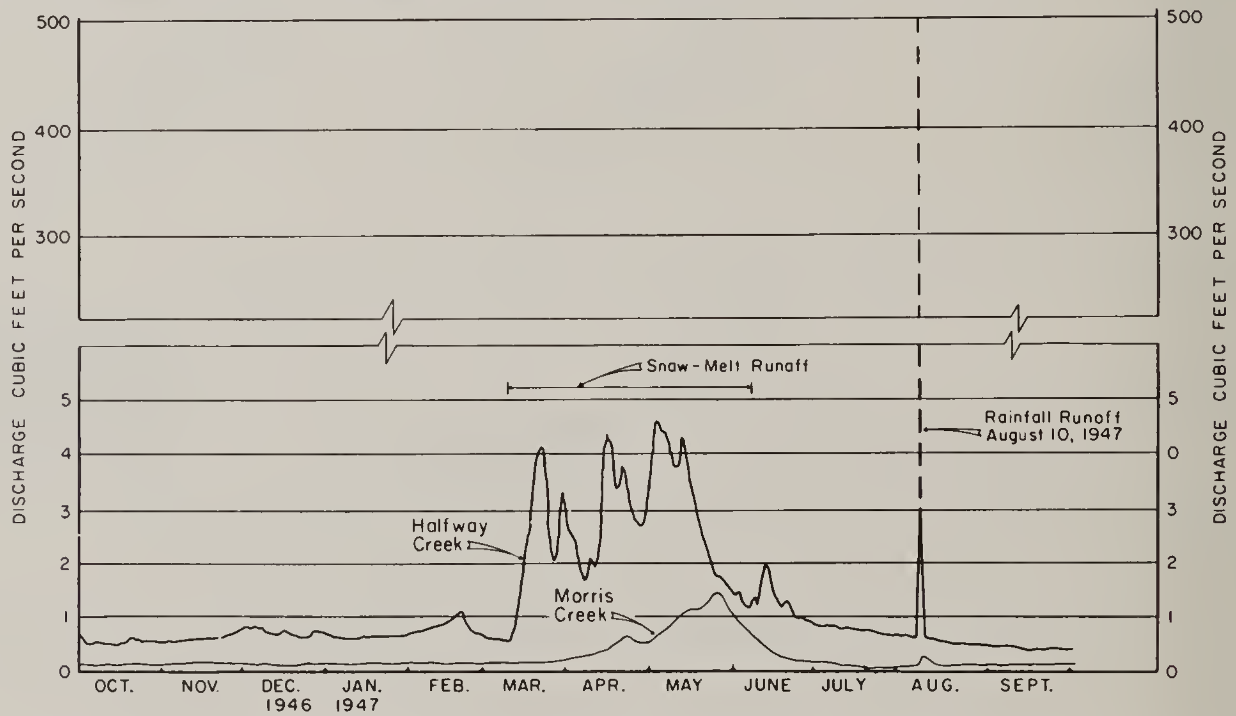


Figure 36. — Stream discharge from snowmelt and from summer rains, Halfway and Morris drainages, which have different watershed conditions. (Davis County Experimental Watershed, Utah)

Stream discharge of Morris Creek, during the August 10, 1947 rainstorm, contrasts markedly with that of Halfway Creek. Here the flow was but slightly increased for only a few hours; discharge increased from 0.12 cubic feet per second to 0.40 cubic feet per second, only a small fraction of the increase attained by Halfway Creek. The well-vegetated slopes of Morris drainage prevented oversurface flow, whereas the 50-acre burned area on Halfway watershed, which had practically no vegetal cover 9 years after the burn, allowed enough oversurface flow to generate a destructive flood.

The measurements and observations on these two watersheds corroborates the conclusions reached regarding cause of the Davis County front floods of 1930; that destruction of vegetation on as little as 10% of the offending watershed area permitted flood runoff during torrential rainstorms.

Watersheds A and B. — At Great Basin, studies of the effect of ground cover changes caused by domestic livestock on surface runoff and erosion were made on two 10-acre watersheds, A and B during the period 1912—1958.

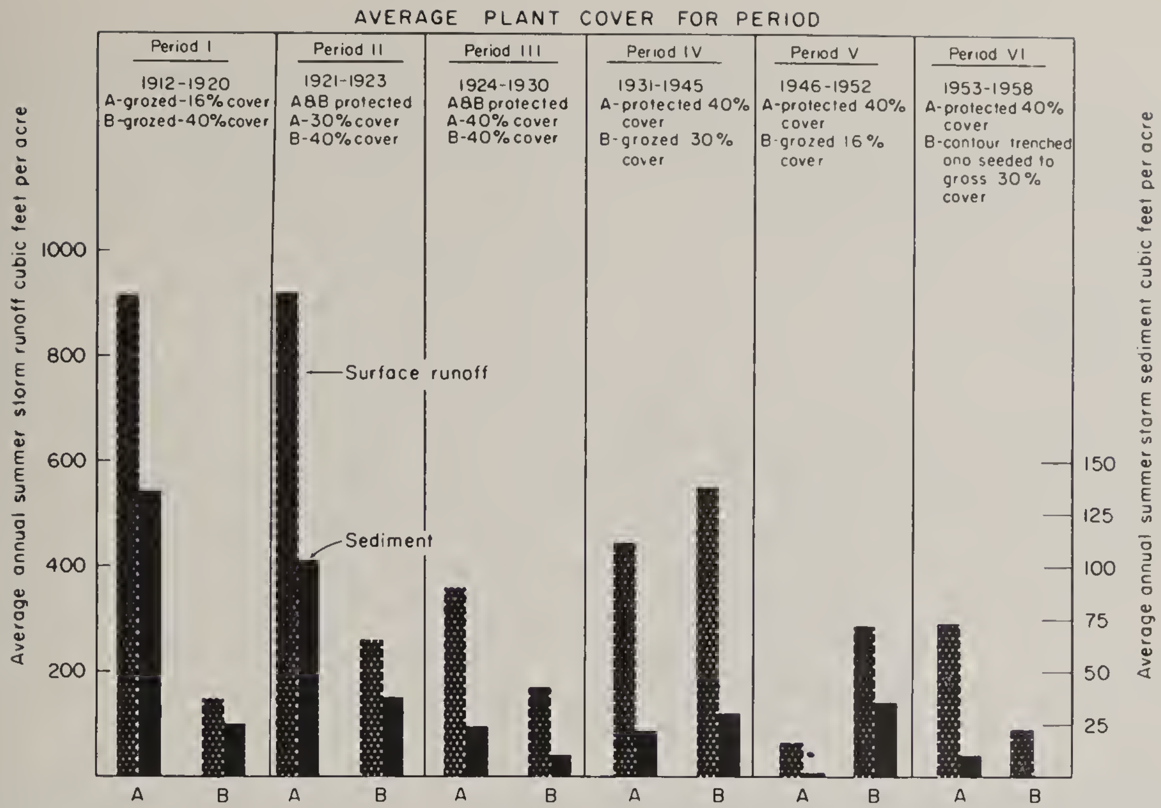


Figure 37. — The effect of plant cover changes on surface runoff and erosion during a 46-year period from A and B experimental watersheds. (Great Basin Experimental Area, Utah)

Before establishment, these two watersheds had a long history of grazing and both were yielding surface runoff and sediment from severe rains. A system of treatment was devised to facilitate comparing the effects of grazing and vegetal cover changes. The history of the experiment is divided into 6 periods. In the first period both watersheds were maintained in the condition that existed at the time the experiments were established. This was accomplished by controlled grazing. Watershed A, in an extremely depleted condition (16 percent plant cover) produced six times more runoff and more than five times as much sediment as did Watershed B (40 percent plant cover). During the second and third periods, vegetation on A improved, resulting in a reduction of runoff and sediment. In the fourth period the cover on B was reduced to 30% by grazing. Immediately, the magnitude of overland flow and sediment production reversed, and B produced more of each than did A.

In the fifth period the density of vegetation on B was reduced to 16% by heavy grazing to render it comparable to the condition of A during the first period. Overland flow and sediment yields increased markedly. Sediment yield which was only 1/5 as much as from A during the first period now increased to 12 times that of A, and runoff increased to four times that of A. Following this period, B was rehabilitated by contour trenching and seeding, while A remained unchanged. Again, the sixth period brought a profound reversal of overland flow and sediment yields — sediment from B dropped to 1/10 that of A and runoff was only 1/3 as much.

This 50-year-old experiment illustrates, as did the Parrish Plot studies at Davis County Experimental Watershed, that rainstorm runoff and soil erosion can be dramatically changed by altering the amount of vegetation and litter cover.

WATER CONSUMPTION BY VEGETATION

It takes water to grow vegetation and consequently the plant cover required to prevent surface runoff and to keep soils stable reduces the water available for streamflow and ground water.

Experiments at the Davis County Experimental Watershed show how average annual precipitation of 52.77 inches for the period from 1947 to 1949 was disposed of on plots supporting aspen trees, shrubs, and grasses.

Factor	Portion of total annual precipitation (percent)
Interception and evaporation from vegetation, and evaporation from snow	7
Used to grow vegetation	35
Available for streamflow, ground water, or deep seepage	58
Total	100

These values apply only to the conditions at this particular location. Differences in kind and density of vegetation, soil characteristics, amount and character of precipitation, and other climatic factors can cause tremendous changes in one or all of these values. For example, water loss by interception may vary from about 5% to 40% of precipitation, and vegetation could conceivably use all precipitation that reaches the ground.

Therefore, the danger in applying the results of studies of consumption use of precipitation from a particular geographic-precipitation-vegetation-soil complex to other complexes is apparent.

USE OF WATER BY PLANTS

Two procedures were used to study the consumption of water by vegetation on mountain watersheds: (1) the determination on plots of the amount of water removed from the root zone by different kinds and densities of plants, and (2) changes in water yield, from complete watersheds having perennial streams, as a result of changes in vegetal cover.

The Soil Moisture Method.—This method involves the following determinations:

a. Total water content of a column of soil when saturated by snowmelt water to its total capillary capacity (field moisture capacity).

b. Total water content in this column of soil at the time of maximum soil moisture depletion in early fall.

c. The amount of rainfall (exclusive of interception) that reaches the soil surface during the growing season.

Water used by vegetation during the growing season then would be: a — b + c. Studies involving this method were made on the 1/10-acre Parrish plots on the Davis County watershed to determine water consumption by, (1) aspen and herbaceous vegetation, (2) herbaceous vegetation only, and (3) loss of water from soil without plants. Measurements were made of total precipitation, interception of precipitation by plants, and soil moisture to a depth of 6 feet during the tree-year period, 1947 to 1949 inclusive.

Water use by aspen-herbaceous vegetation.—This study was conducted on 1/10-acre plot No. 9 at 8,200 feet elevation. The results are shown in figure 38. All figures are inches of water and three-year average.

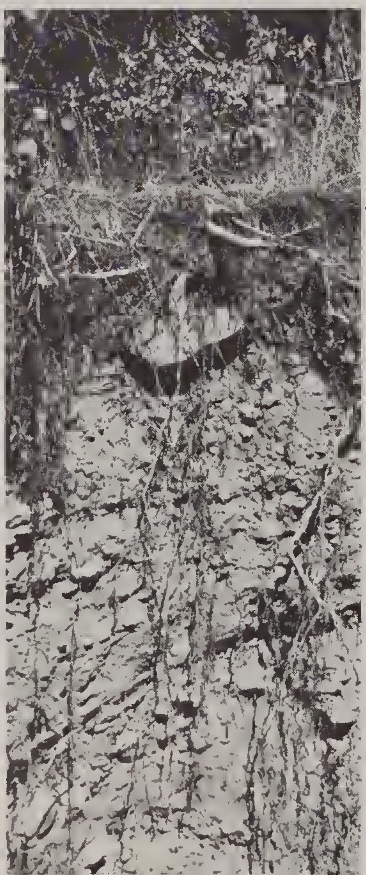


Figure 38. Disposition of precipitation on an aspen-herbaceous site with soil more than six feet deep. (Davis County Experimental Watershed, Utah)

ITEM	Water (Inches)
Annual Precipitation	52.77
Interception and evaporation from vegetation	1.16
Evaporation from snow	2.50[1/]
Surface runoff	0.01
Winter transpiration by aspen (est.)	1.00
Water entered the soil	48.10
Water from snowmelt and rain stored in the soil and used to grow vegetation	17.70
Water not stored in the soil percolated through the soil and became available for streamflow, ground water, and deep seepage	30.40

1/ From Great Basin studies

Water use by herbaceous vegetation and losses from bare ground.—Aspen trees were cut from Plot No. 8, and all vegetation and litter were removed from Plot No. 7. Results for the three-year period are shown in Table 5.

Water lost during the growing season from the soil column to a depth of six feet was 14.83 inches from the plot with excellent herbaceous plant cover and 11.21 inches from the plot with no plant cover. Thus, the water cost of growing herbaceous plants was only 3.76 inches more than if the ground had been bare. Loss of the 11.21 inches af water from the bare plot presumably was largely by evaporation from the soil surface, with some translocation during the growing season. There are good reasons for assuming that, as the ground is made bare by the thinning of plant cover, evaporation of water directly from the soil surface — a nonproductive loss — increases.

Table 5.—Disposition of precipitation on bare and vegetatively covered ground (Davis County Experimental Watershed, Utah)

Factor	Herbaceous Vegetation (Inches)	Bare Ground (Inches)
Precipitation	52.77	52.77
Interception	0.77	0.00
Evaporation from snow	2.75[1/]	3.00[1/]
Surface runoff	0.02	0.40
Entered the soil	49.23	49.37
Lost from soil	14.83	11.21
Available for streams, ground water, deep seepage	34.40	38.16
Bare minus herbaceous	3.76	

1/ From Great Basin studies

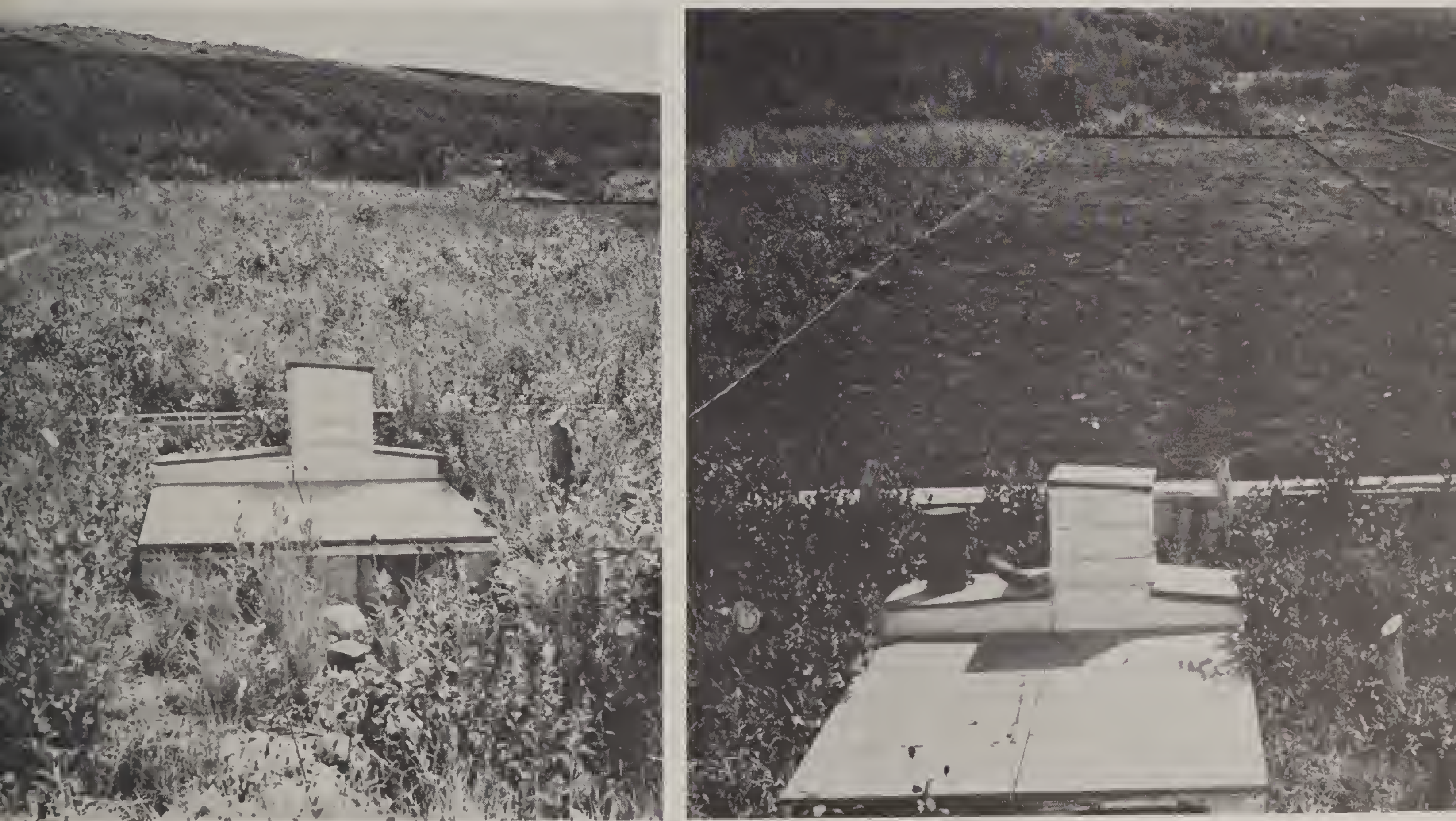


Figure 39. — Plots used for determining disposition of precipitation on vegetation-covered ground and bare ground. (Davis County Experimental Watershed, Utah)

Water used by grass and by dandelion-sweet sage. — Experiments have been conducted at Great Basin, elevation 9,500 feet, to determine the amount of water used to grow dense grass as compared to mixed herbs which have low watershed protection and forage value. Results for 1952 are shown in Table 6.

Figure 40. — One inch of water produced 284 pounds of smooth brome grass as compared to 80 pounds per inch for dandelion-sweet sage. (Great Basin Experimental Area, Utah)

Table 6.—Relation of forage production to water consumption

Range cover	Evapotrans-piration	Forage Production	
	(Inches)	(Lbs. acre)	(Lbs. acre) (per inch water)
Smooth brome	11.33	3,220	284
Timothy	10.54	1,440	137
Kentucky Bluegrass	9.47	1,980	210
Dandelion-sweet sage	8.96	715	80

Water consumption by a stand of dandelion-sweet sage was about three and one-half (3½) times that of smooth brome per pound of forage produced. This appears to be related to the fact that the roots of these low forage producers occupy and extract water from about the same soil volume as those of the high forage-producing grasses, and that sparse foliage allows considerably more water loss by direct evaporation from the soil surface than do the dense grasses that shade the ground.

The effect of changes in vegetation on streamflow. Experiments, using entire watersheds, were conducted at several experimental areas to determine how changes in the amount of vegetation affect water yield. Measurement of precipitation and streamflow were made for a period of years (the calibration period). Then the plant cover was changed rather drastically and the measurements were continued for a second period of years (the test period).

Mixed woodland, brush and grass.—Twenty-one years of streamflow records from Parrish Creek and Centerville Creek watersheds in Davis County provide the basis for determination of water yield as influenced by alter-

ing the vegetation. Plant cover on Centerville Creek watershed has been maintained in excellent condition, since settlement in 1850. Vegetation on Parrish Creek drainage, on the other hand, was seriously depleted by excessive grazing and fire by 1930, and the watershed produced devastating floods as already reported.

As a result of protecting the Parrish Creek watershed from grazing and through contour-trenching and seeding of about 175 acres in the upper basin in 1936, a protective plant cover of aspen trees, brush, and grass was restored by 1958. In addition, trees and brush were re-established along about three miles of stream channel which had been swept clean of all vegetation by the 1930 floods.

Streamgaging stations were installed on both creeks in 1936 and precipitation gages and snow-measuring stations were established in the upper basins.

In 1958, a time-trend analysis of actual water yield from Parrish Creek compared to that from Centerville Creek as the control, showed that water yield from Parrish Creek had declined by a total of 2.71 area inches, or 310 acre-feet for the 1,377 acre watershed.

Table 7.—A summary of monthly, quarterly, and annual changes in water yield from Parrish Creek as compared to Centerville Creek for the period 1937-58

Period		Change in Parrish Streamflow
		(Area Inches)
Month	—October	—0.06
	November	— .10
	December	— .07
	January	— .09
	February	— .10
	March	— .27
	April	— .83
	May	— .95
	June	— .22
	July	— .13
	August	— .10
	September	— .12
Quarter	—October-December	— .24
	January-March	— .53
	April-June	—1.51
	July-September	— .35
Annual	—	—2.71

The decrease in water yield from Parrish Creek is attributed to increase in vegetation on the watershed, mainly on the formerly depleted flood-source areas, and reestablishment of riparian vegetation along the channel. The greatest decrease in Parrish Creek streamflow occurred in the spring when water supplies are generally greatest in relation to demand.

The flood threat as a result of plant depletion from Parrish Creek has been eliminated by the contour-trenches and restoration of vegetation on the watershed slopes. Decrease in streamflow of 2.71 area inches annually is regarded as the cost, in water, of protection from floods and sedimentation, stabilization of the age-old soil, increased forage, improved wildlife habitat, and protection of fishery and recreation values along the stream.

Lodgepole pine. — Effect of cutting lodgepole pine on total water yield has been studied by the Rocky Mountain Forest and Range Experiment Station at its Fraser Experimental Watershed in the high Colorado Rocky Mountains. The study was started in 1943 on timbered watersheds of Fool Creek and East St. Louis Creek. Following a long period of calibration, 40% of the area (285 acres) of Fool Creek (714 acres) was clear-cut in alternate contour-strips from 1 to 6 chains wide. Water-yield increases shown in table 8 were assumed to be the difference between the predicted yield based on the calibration data and actual yield after treatment.

Table 8.—Water yield increases from cutting lodgepole pine in Fool Creek, Colorado

	Predicted Yield	Actual Yield	Increase
Years	(Inches)	(Inches)	(Inches)
1956	11.4	15.6	4.2
1957	19.6	23.0	3.4
1958	11.4	13.5	2.1
1959	10.5	13.6	3.1

These water yield increases could logically be ascribed to treatment given the 285 acres of the 714-acre watershed. When this yearly increase in streamflow from Fool Creek watershed is prorated to the 285 acres that were clear-cut, the approximate increase in water

yield from the treated area for each year of treatment is 10.5 inches, 8.5, 5.2, and 7.8 area inches respectively.

The published results of the Fool Creek Study state that, "most of the increase in yield occurred during the spring freshet period of May and June, but there has also been a small increase in the summer and early fall months. Each year the early rise of Fool Creek is more rapid than formerly, and in three years the spring peak has been higher than it would have been had the timber not been cut."

White fir—Douglas fir.—The effect on total water yield of replacing white fir—Douglas fir forest with perennial grass also has been studied by the Rocky Mountain Forest and Range Experiment Station at its Workman Creek Experimental Watershed in Arizona. The treated area consisted of 80 acres on the North Fork of Workman Creek, a 248-acre watershed. Preliminary results are shown in table 9.

Table 9.—Preliminary results of forest tree removal on water yield, Workman Creek, Arizona

Year	Precip. Inches	Water Yield: Expected Inches	Water Yield: Actual Inches	Water Yield: Increase Inches
1958-59	23.8	0.9 1/	1.4	0.5 2/
1959-60	43.0	4.4 1/	6.4	2.0

1/ Based on pre-treatment regression

2/ Not statistically significant

The water yield increases were believed to be a result of treatment of 80 acres of the 248-acre watershed. Accordingly, when the yearly increase in streamflow from the 248-acre watershed is prorated to the 80 acres that were clear-cut and planted to grass, the approximate increase in water yield from the treated area would be 1.6 inches (69%) and 6.2 inches (68%) for the respective years of measurement. "Additional years of observation, . . . will be required for adequate evaluation of treatment. Thus, the increased water yields reported are indicative and not conclusive."

IS WATERSHED TREATMENT TO INCREASE WATER YIELD DESIRABLE?

In discussing this question, a number of points should be made clear at the outset. First — Most of the studies reported have been conducted under controlled conditions without regard for cost or the practical application of the results. Second — Treated areas will not long stay "treated" because when vegetation is removed, plants will soon invade due to availability of soil moisture. Accordingly, in addition to the cost of the original treatment, there will be a periodic cost of maintaining the post-treatment conditions. Third —The hazards of accelerated soil erosion and sedimentation, as a result of drastic vegetation changes that may accompany treatment, must be fully recognized and preventive measures taken. We cannot afford to "sell" age-old soil to "buy" small annual increments of water.

Manipulation of vegetation to increase water yield is definitely not a simple operation. Nevertheless, the results of research have been used to support the belief that by the "simple" process of removing trees and other vegetation from high watersheds, significant quantities of additional water can be produced.

It is quite certain that manipulation of vegetation can result in increases in water yield in certain areas without watershed or channel damage, if the program is properly conceived, executed with adequate guides and controls, and followed by proper management. Obviously, the danger lies in proceeding too fast and with too little knowledge of the complicated problems involved, especially under pressure for increased water supplies in all parts of the country. Untimely, ill-conceived, and poorly executed programs are quite likely to be disappointing if not destructive. They could result in considerable damage to watershed soils by erosion, and thereby arrest in infancy a program that, in some places, may have considerable promise of success.

ANALYSIS OF SOME DESTRUCTIVE FLOODS

Armed with the information gained from research, and from critical observation of the condition of vegetation and soil on many watersheds, analyses were made of a number of destructive floods that have occurred in the Intermountain West. Each analysis involved

investigation to determine (1) nature of the flood deposits and damages, (2) extent of flood water discharge and erosion on the watershed slopes and in stream channels, (3) the relation of vegetation and litter to flood runoff and erosion on watershed slopes, (4) character of precipitation, and (5) the assignment of flood causes.

As a result of these investigations, it was found that floods fall into three groups: (1) rainstorm floods that followed destruction of vegetation on the watershed—"dry mantle floods," (2) "wet mantle floods" that occurred because the watershed's soil had become saturated with water by prolonged rainfall and snowmelting, following which additional water percolates relatively quickly through the soil to streams, and (3) "frozen ground floods" that occur when frozen soil prevents rain and melted snow water from entering the soil, thus allowing oversurface flow.

SUMMER RAINSTORM FLOODS

Davis County, Utah. — Rainstorm floods of the mud-rock type (dry mantle floods) from the west face of the Wasatch Mountains in Davis County, Utah, were first reported from Bairs, Kays, and Holmes Creeks, east of Kaysville in **The Weekly Reflex,** Kaysville, Utah, August 8, 1912. Then, on August 14, 1923, similar floods occurred from Farmington, Steed, and Ford Creek drainages. Six people camped in Farmington Canyon were killed and damage to homes, farms, highways, and water systems was great.

The next major rainstorm floods occurred from Parrish, Barnard, Davis, and Ford Creeks in the Farmington-Centerville area in the summer of 1930. Devastation in the track of the floods was tremendous and damage to property in a 6-mile area from Centerville to Farmington amounted to about $1,000,000 from 1923 through 1930.

Figure 41. — Parrish Creek rainstorm flood of July 10, 1930, Centerville, Utah, and one of the numerous runoff sources on the Parrish Creek Watershed.

As a result of an aroused public, Governor George H. Dern appointed a 17-man "Flood Commission" with foresters, livestockmen, engineers, bankers, geologists, and lay-citizens as members. Beginning with the flood deposits in the valley, the commission specialists analyzed each flooding drainage from bottom to top, following the flood courses back through the freshly cut channels and their tributaries to the high watershed lands where the rains fell that generated the floods. In every case, they found a striking relationship between the flood runoff and the density of vegetation.

Their descriptions of conditions in the head of Ford Creek drainage hold true also for Farmington, Parrish, Barnard, Steed, and Davis Creek watersheds:

> *About one-fourth of the total area of the upper zone at the head of Ford Creek . . . is nearly denuded of vegetation and litter . . . It was strikingly evident that the flood originated on the barren or nearly barren areas in the upper zone . . . Most of the numerous gullies of all sizes which joined to form the main channel, when traced to their source, were found to originate on the areas where there was little or no vegetation . . . Even the gentler 3 to 5 degree slopes, when sparsely vegetated, had numerous gullies. (Bailey et al 1934)*

Although the amount of rainfall in the upper watersheds was not known, well-vegetated slopes, intermingled with bare spots that were ripped and gullied by oversurface flow, showed no evidence of having contributed any water to the floods. They had infiltrated all the rain that fell — a convincing demonstration that adequate cover of vegetation and litter had prevented flood runoff and soil erosion, even on the steepest slopes during torrential rainfall.

Another striking demonstration of the effect of adequate plant cover in preventing rainstorm floods was provided by the generally well-vegetated Centerville Creek drainage, immediately south of Parrish Creek drainage, which produced no mud-rock floods in 1923 or 1930; nor has Centerville Creek drainage produced any such floods in recent geologic time. That rainfall was heavy on this watershed was evident by the extensive gullying on the small areas where vegetal cover had been reduced in density. Very small patches on its slopes were gullied in the same manner, and to the same degree, as the more extensively denuded flood-source areas of neighboring basins. The damaged areas on the slopes of Centerville Creek watershed were not extensive enough to produce flood runoff. Runoff from these spots never reached the channel but was absorbed by the soil on the densely plant-covered areas.

Centerville Creek drainage did not flood because its plant and soil mantle, that had maintained control of surface runoff and soil stability over the ages, had not been impaired by overgrazing as had the other drainages. Years ago, the people of Centerville acquired part of the upper portion of the drainage and arranged with owners of the remainder of the land for conservative grazing use on the entire watershed. As a consequence, the plant cover and soil mantle have been adequate to prevent flood runoff during torrential summer rains.

Manti, Utah.—Probably the first very large rainstorm floods to come to public attention in Utah were from Manti Creek drainage at Manti, Utah, about the turn of the century.

Not much is known, specifically, about conditions that existed on the watershed at the time but there was sufficient understanding to prompt the people of Manti to request Congress for managemnt of the federally-owned watershed land above the town. As a result, the Manti National Forest was established in 1903. In 1910, 40 residents of Fairview, a few miles to the north, petitioned the Secretary of Agriculture to add a block of watershed land above their town to the Manti National Forest. The petition stated that the land was "overcrowded with sheep, causing the destruction of the vegetation and thereby . . . serious injury to the watershed, draining into the . . . Gooseberry and Cottonwood Irrigation Co.'s Reservoir. As the water from this reservoir is our main supply for irrigation, any injury to its watershed is a serious menace to our farming interests."

Effective management of livestock and

Figure 42. — Manti Creek flood of August 18, 1898. (Manti, Utah)

game, seeding, and fire prevention on the Manti National Forest have resulted in improved vegetation and litter cover. During the past 50 years there have been no floods from Manti Canyon comparable to those that occurred for about a decade near the turn of the century. However, by comparison of cover conditions on parts of the watershed with areas where watershed conditions and rainfall amount and intensity have been accurately measured, and vegetation-precipitation-runoff relationships established, it is believed that serious erosion and floods could occur if the areas in question were to be subjected to intense rainstorms such as have been recorded at nearby precipitation stations.

Caution in drawing conclusions about the adequacy of improved plant cover in flood prevention should be applied to all watersheds where soil and plant deterioration have occurred. Experience has shown that substantial watershed improvement can occur and still be considerably short of providing adequate plant cover for flood prevention.

Mt. Pleasant, Utah.—Pleasant Creek at Mt. Pleasant, Utah, produced very serious floods in 1918 and 1946. One person was killed in the 1918 flood, but information is scanty on property damage, rainfall, and watershed conditions. Soon after the flood, two small flood catchment basins were constructed near the canyon mouth, but these neither eliminated the flood causes nor prevented flood damage to Mt. Pleasant as the flood of July 24, 1946 demonstrated.

Extensive investigation of the 1946 Pleasant Creek flood by a U. S. Department of Agriculture Flood Control Survey crew working in the area when the flood occurred revealed that the flood originated on about 1,773 acres of watershed land severely gullied and depleted of vegetation. Although the soil had been relatively dry to a depth of two feet to four feet, indicating considerable storage ca-

Figure 43. — Pleasant Creek flood of July 24, 1946. (Mt. Pleasant, Utah)

pacity for rainfall, only enough water had entered to wet the upper 2 to 3 inches. Because of the lack of vegetation which aids infiltration, a large part of the rainfall rushed over the soil surface and soon concentrated in rills and gullies to form destructive floods. Extensive damage was done to homes, business property, roads, and farms in and near Mt. Pleasant by the 1946 flood.

Willard, Utah.—Serious rainstorm floods of the mud-rock type came from Willard drainage, at Willard, Utah in 1923 and 1936. The 1923 flood was the first of its kind since settlement about 1850. Serious depletion of vegetation had occurred in the upper Willard basin due to heavy grazing and fire. (Paul and Baker 1925.) The municipal power plant was destroyed and highway No. 91 was made impassable to vehicles by sediment and boulders. Homes were filled with mud and several hundred acres of valuable orchard land were covered with mud and rocks.

Figure 44. — Willard Creek flood of August 14, 1923. (Willard, Utah)

Following the flood of July 31, 1936, a survey was made of watershed conditions in the upper basin which showed that timber, brush, and herbaceous vegetation had been seriously damaged by fire and excessive grazing on about 1,400 acres of watershed. It was here that the floodwater originated as a result of summer rainfall of unknown intensity and amount.

Salt Lake City.—The most damaging rainstorm flood ever reported for Salt Lake City occurred August 19, 1945. The flood originated on less than one square mile of low-lying hills, directly north of the city cemetery, that had been completely denuded of vegetation and litter by fire in 1944.

A study of this flood revealed, very strikingly, the effects of plant cover destruction on flood runoff. Runoff, as evidenced by gullies and rills on the slopes, was confined entirely to the burned area. There was no evidence of overland flow where dry cheatgrass and the accumulated litter had not been burned; whereas, on the burned areas immediately adjacent, runoff had been very great. Extensive damage was done to the city cemetery, homes, streets, and other property.

There were no rain gages on the area, but

Figure 45. — Salt Lake City foothill watershed. Unburned area (left), and burned area (right). (Flood of August 19, 1945, Salt Lake City, Utah)

evidence suggests total rainfall was about 1.75 inches or more, with very high intensities. Peak flood discharge was estimated at about 4,000 cubic feet per second per square mile of land — the highest reported for any Wasatch Mountain rainstorm flood.

Boise, Idaho.—The most serious rainstorm flood to strike Boise, Idaho, in its 100-year history, occurred on August 20, 1959. A deluge of water, mud, and rocks estimated at more than 1,000 c.f.s. flooded 11 miles of the city's streets and caused extensive damage to homes, streets, and personal property.

The flood runoff originated on about 5,000 acres of watershed lands on which the vegetation and litter had been drastically reduced by fires in 1957, 1958 and 1959. The 10,000-acre fire on August 3, 1959, in Cottonwood and Picket Pin drainages occurred only 17 days before the flood and consumed practically all vegetation on the surface of the ground. There was nothing on the ground to protect the soil from the impact of the torrential rain or to retard the surface runoff from the watershed slopes. The gullied hillsides and scoured channels gave glaring evidence of the large amount of flood runoff.

It is reported that many years of heavy

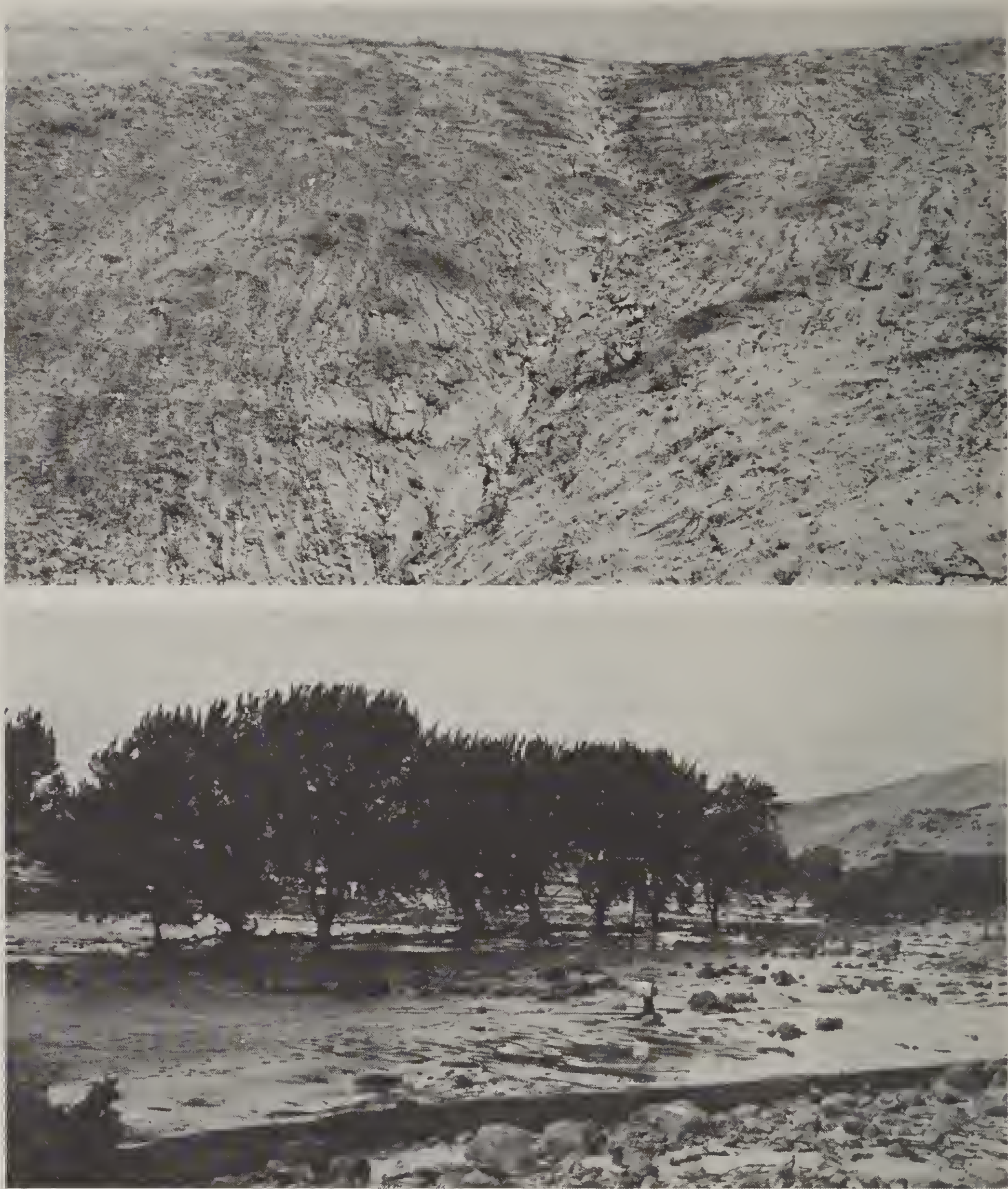


Figure 46. — Flood runoff patterns that were etched into soil of burned slopes on the Boise front watershed, and flood debris in the valley. (Flood of August 20, 1959, Boise, Idaho)

grazing was an indirect contributor to the flood because this resulted in conversion of the more fire-resistant perennial grasses to cheatgrass which is a flash-fire type.

Galena Creek, Nevada.—Summer rainstorm floods also have been recorded from watersheds in Nevada of which the 70,000-acre Galena Creek, is an example. Very severe floods occurred in 1952 and 1956.

The floods originated on about 3,000 acres of land in the upper watershed with a long history of destructive logging, unregulated grazing, and fire. The flood of July 20, 1956, killed four people where the flood crossed Mt. Rose Highway. Roads, campgrounds, and some pasture land were damaged severely.

WET MANTLE OR SNOW-MELT FLOODS

In contrast to summer rainstorm floods that occur when much of the torrential rainfall is discharged from the slopes by overland flow, wet mantle floods occur when prolonged rainfall and water from melting snow exhaust the soil's water storage capacity, so that additional rainfall and snowmelt water percolate quickly through the soil to streams.

Several floods of this character have occurred from the Truckee River, Nevada, and California drainages and from the Wasatch Mountains of Utah.

Truckee River, Nevada.—The Truckee River floods which did extensive damage in Reno, Nevada, and vicinity, in November, 1950, December 1955, and February 1963 are excellent examples of wet mantle floods, involving prolonged rainfall and snowmelt, and a saturated soil mantle. The flood of December, 1955,

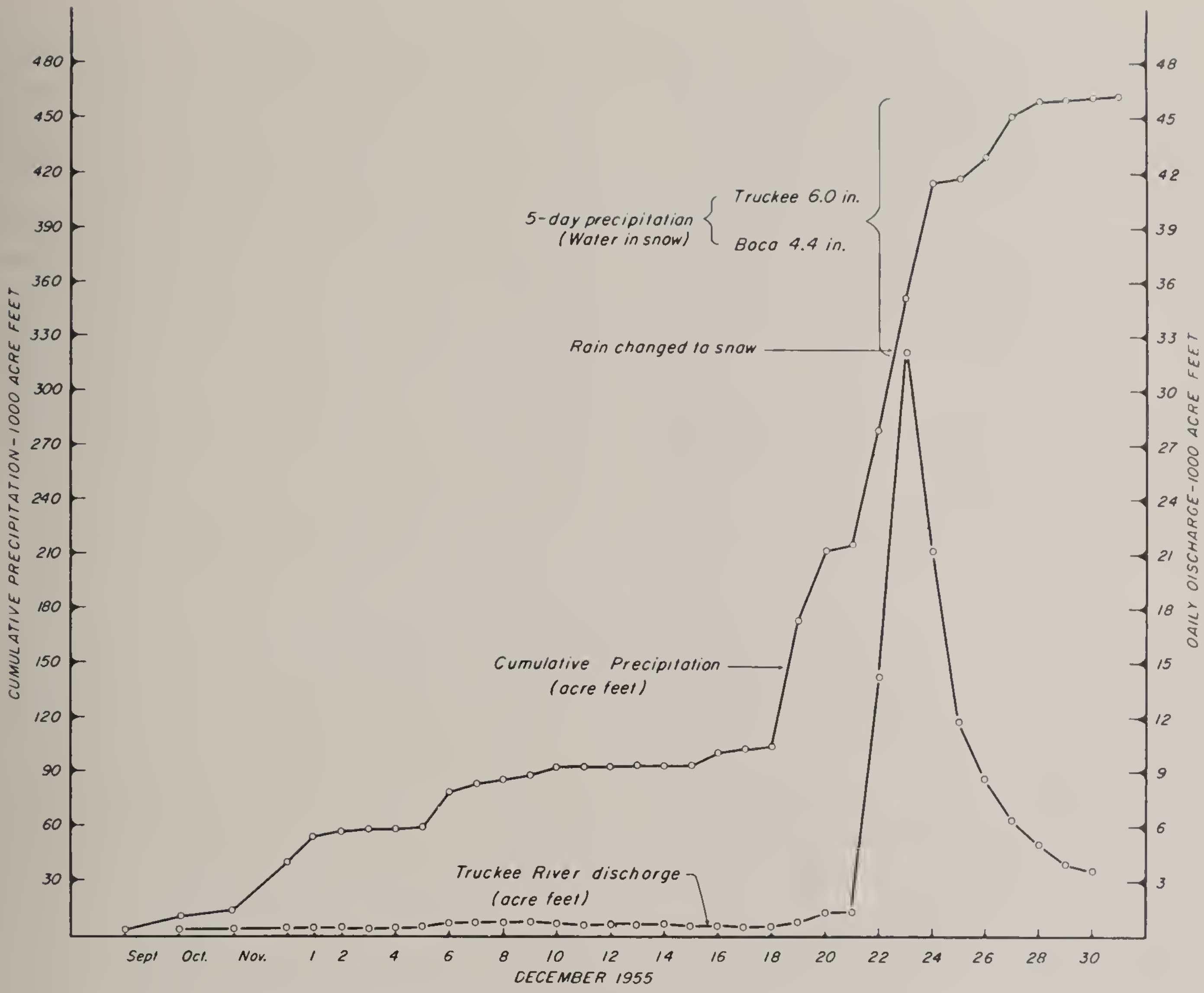


Figure 47. — Cumulative precipitation and its relation to discharge of the Truckee River at Reno, Nevada, during the flood of December 1955.

illustrates some of these relationships.

During the period September 1 to December 21, inclusive, precipitation (rain and snow) on the 382 square mile area from which the flood came, amounted to 218,350 acre-feet, or an average of approximately eight inches over the watershed. During this period, daily discharge of the Truckee River at Reno rose gradually from about 330 acre-feet on September 1, to 1,626 acre-feet on December 21. By December 21, practically all of the snow had melted, augmented by warm rains. Since there were no sharp increases in stream discharge following heavy rains and snowmelting from September 1 to December 21, it is assumed that much of the precipitation prior to December 21, was stored in the watershed soil.

A marked change in the magnitude of discharge occurred on December 22 and 23. Up to this time, most of the precipitation and snowmelt had been stored in the soil. But when the soil became saturated, additional water percolated rapidly through the soil giving rise to flood discharge. Rainfall on these days was 8.65 inches in the Sagehen-Truckee area and 3.82 inches at Boca Dam. As a result, daily discharge increased from 1,626 acre-feet on December 21 to 32,130 acre-feet on December 23. Peak discharge on the 23rd was 20,800 c.f.s. (41,300 acre-feet) as reported by U. S. Geological Survey.

Rain changed to snow on December 24 and by December 28 deposited a pack containing 6.0 inches of water in the Sagehen-Truckee area and 4.4 inches at Boca. Since this precipitation was stored as snow, and therefore,

unable to contribute to streamflow, the Truckee River receded rapidly, and in a few hours the flood crest had passed. Had not the rain turned to snow about the time peak discharge occurred, the flood could have increased by 5,000 to 10,000 c.f.s., because of the absence of water storage capacity in the soil.

Utah Spring Floods.—Some very unusual and destructive spring snowmelt floods occurred from the Wasatch Mountains in northern Utah in 1952, and again in 1955. During the height of the 1952 floods, ten two-man teams, made up of experienced foresters, geologists, and engineers examined the watersheds to determine the origin of the flood waters and whether the flood-water was supplied by oversurface flow, or seepage flow to streams. Without exception, it was found that snowmelt water was disposed of by infiltration and percolation. The floods occurred because the soil became saturated and the additional water from snowmelt moved by percolation to streams. Vegetation, it was concluded, had little, if anything, to do with the floods. The rate of snowmelt was less than the infiltration and percolation capacities of the soil, even in the absence of a plant cover.

In general, conditions that contributed to the Utah floods were: (1) a very deep and extensive snowpack, (2) unusually cold spring weather that retarded snowmelt, resulting in a very high percentage of the watersheds remaining snow-covered until late spring, (3) high temperatures during the melting period, and (4) an unusually large contribution of water from low-elevation watersheds that normally contribute little or no water to spring streamflow.

Columbia River Floods.—During the devastating floods in the Columbia River Basin late in May, 1948, the U. S. Department of Agriculture sent a 20-man task force to the basin to study flood causes. These men examined the Columbia Basin by air, auto, horseback, and on foot, made careful observations as to watershed conditions, and gathered data on snowpack (depth and extent of coverage), rainfall, and temperature. They concluded that: (1) the flood was of the "wet mantle" variety, (2) excessive oversurface flow of water came only from the palouse wheat lands and similar areas, and from a few seriously disturbed areas in the forests, (3) disposition of water from snow on virgin timber and second growth timber lands, and to a limited extent on burned-over areas, was by infiltration and percolation to streams.

Though practically all water came from seepage flow, even where fires had eliminated the forests, these treeless areas contributed heavily to flood peaks because snow melted faster and interception was less than in the forests. The factors that contributed to the Columbia River floods of 1948 were much the same as those related to the Utah spring floods of 1952 and 1955.

FROZEN SOIL FLOODS

During the winters of 1961-62 and 1962-63 certain areas in Utah, Idaho, and Nevada experienced serious floods that have been attributed to frozen ground. The general contributing causes for such floods are about as follows: (1) in the winter, absence of a snow cover often allows the soil to freeze to a depth of four to six inches, (2) snow accumulates on frozen ground and with the advent of warm rains substantial quantities of water are released that cannot infiltrate into the frozen soil, and (3) rapid oversurface flow occurs that may produce high flashy streamflow, or it may collect in low, poorly drained areas to form temporary ponds or lakes.

Floods caused by frozen ground in the winter and spring of 1962 and 1963 caused considerable damage at Battle Mountain, Nevada, and Stone and Bancroft, Idaho. Also, towns along the Portneuf River in Idaho, particularly Lava Hot Springs, McCammon, and Pocatello, experienced serious flood damage in 1962 and 1963. Field examination of the flood sources showed frozen ground to be the principal cause of the floods.

The extent to which good cover of vegetation, litter, and organic top soil reduce soil freezing is not too well understood. Observations indicate, however, that a cover of vegetation and litter reduces the depth of freezing, and in some cases produce a spongy, porous kind of ice structure that actually increases the infiltration capacity, thus reducing the chances of oversurface flow and floods.

REPAIRING DAMAGED WATERSHEDS

Damage to watershed lands in the Intermountain West due to excessive grazing by livestock and big game, improper road location, construction and maintenance, placer and dredge-mining, fire and timber harvesting is extensive. Because of the nature and extent of damages caused by overgrazing, restoration of watershed lands damaged by grazing is a most pressing problem. Accordingly, this discussion will be limited to lands used for grazing.

These grazed mountain lands consist of numerous complexes involving topography, climate, soil, vegetation, and animals, one or all of which may vary greatly in short distances as a result of changes in aspect, slope, soil, and elevation. Because of the variable nature of watersheds, the determination of condition and trend, and the application of appropriate remedial measures require a working knowledge of ecology, soils, climate, and forest hydrology. Training and experience is necessary before the ecologic and hydrologic condition of a mountain watershed can be recognized and evaluated.

Factors and indicators used in determining condition and trend of watersheds must be carefully selected and evaluated or wrong conclusions can be drawn. An example of an indicator that is often cited and which can

Figure 48. — This slope has adequate feed for sheep, but the vegetal cover has been so reduced that the area has become a source of flood runoff and downstream sediment from the eroding soil. (Sawtooth Mountains, Idaho)

Figure 49. — Satisfactory watershed conditions can be maintained on well-managed lands that are suitable for grazing. (Humboldt National Forest, Nevada)

be entirely wrong, is that livestock in good flesh indicate satisfactory range-watershed conditions. Experience has taught that there is no relationship between the amount of vegetation necessary to produce fat livestock and game on steep watershed lands and the amount of vegetation required to prevent oversurface flow and accelerated soil erosion.

One good plant per square yard may supply sufficient forage to produce fat sheep and cattle, but it is woefully inadequate to prevent rainstorm floods. For example, during the period 1923 to 1930 when rainstorm floods caused about $1,000,000 damage in Davis County, Utah, excellent fat lambs and fat beef were produced on the offending watersheds. Then, too, studies have shown that denudation of as little as 10 percent of the watershed can cause destructive erosion and floods even though the other 90 percent may be well-vegetated with abundant forage.

WHAT DOES RESTORATION INVOLVE?

Watershed restoration, briefly stated, is the job of restoring the impaired productive and hydrologic functions of the land, that have been damaged by excessive use and by fire. Damage consists of: (1) reduction or destruction of the plant and litter cover, (2) loss of soil fertility, (3) loss of the soil body by sheet and gully erosion, and (4) changes in the micro-climate — that important climate at the level of the soil and lower strata of the vegetation which is highly important to the establishment of new plants, and thus to the perpetuation of the stand.

Figure 50. — Congressional committee inspects seeding done with public funds on mountain watershed. (Davis County Experimental Watershed, Utah)

RESTORATION MEASURES

Watershed restoration measures that have been effective in the intermountain region are of three general kinds:

1. Those that involve only a properly designed and executed management program for livestock and big game.
2. Seeding of grasses and shrubs, and an adequate management program.
3. Structural measures such as contour-trenches and seeding to stabilize the soil, followed by proper management. Where gullies are too large to be controlled by contour-trenches, special gully-control structures may be necessary.

MANAGEMENT ONLY

Management programs designed to restore damaged watersheds include practices such as: (1) adjustment of livestock numbers and season of use to grazing capacity, (2) rest and rotation grazing, and (3) under certain conditions, complete elimination of use.

Unfortunately, management changes to achieve restoration of satisfactory watershed conditions may result in temporary inconvenience or economic loss to livestock owners through restricted grazing use. Viewed over the long run, however, early corrective measures may be cheapest to users and to society because advanced stages of deterioration often require expensive structural measures in the restoration process, followed by longer periods of nonuse, even permanent exclusion, depending on the severity of damage.

SEEDING AND MANAGEMENT

When deterioration of the plant cover has advanced to the stage where natural seeding, even under protection from grazing, will not be rapid enough to prevent excessive oversurface flow and soil erosion, artificial seeding becomes necessary. This must be followed by complete protection usually for 3 to 5 years, and thereafter use must be carefully managed to insure the maintenance of sufficient vegetation to prevent rainstorm runoff and soil erosion.

CONTOUR-TRENCHING AND MANAGEMENT

When watershed deterioration has progressed to the point where extensive gully systems have been made by torrential rainstorm runoff and floods, restoration may require contour-trenches, seeding, and management. However, studies of the relation of watershed conditions to rainstorm floods make possible the delineation of areas that are potential flood producers. Contour-trenches should be constructed on such lands before damaging floods occur.

Figure 51. — Seeding and management restored this damaged watershed. (Above, 1930; below, 1945.) (Davis County Experimental Watershed, Utah)

Contour-trenches are ditch-like structures which are partitioned by dams at intervals of 20 to 30 feet.

As a result of previous research and of special studies conducted for four years throughout the State of Utah, the contour-trench system of flood and erosion was developed.

The principle of contour terracing as a soil conservation measure is very old, but the use of trenched contour-terraces on high range watersheds in the West for the prevention of devastating floods and soil losses, and the method of construction represent, it is believed, a new approach in its application. The object is to get water into the ground where it falls, thus preventing surface runoff and consequent soil losses, and also to create favorable moisture conditions in the soil to hasten the restoration of the plant cover which otherwise might be too slow to meet the control problem. (Bailey and Croft, 1937)

Figure 52. — Building coutour-trenches in 1956 on the Uinta National Forest, Utah.

Figure 53. — Newly constructed coutourtrenches (left); three years after construction (right). (Manti-LaSal National Forest, Utah)

The size and frequency of trenches depends on many factors such as depth and character of the soil, degree of slope, and the amount and intensity of precipitation expected. Contour-trench systems must be designed and constructed so as to prevent surface runoff from the treated slopes when torrential rains occur.

Trenches are seeded to desirable grasses to stabilize the soil loosened in construction, and sometimes between trenches when the residual plant cover is inadequate for soil protection.

Contour-trenches have been used in watershed restoration in the Intermountain Region of the Forest Service, on 83 projects involving treatment of 30,000 acres of watershed land. When installed according to specifications, they have been effective in preventing flood runoff even from some of the most intense rainstorms recorded in the area. They also have been used with success in other western areas and in several foreign countries.

Figure 54. — Contour-trenches are used to rehabilitate valuable watersheds. (Left above, Boise, Idaho; right above, Provo, Utah)

A LOOK AHEAD IN WILDLAND MANAGEMENT

Beginning in 1897, National Forests (until 1907 called "forest reserves") were established over a period of years to secure favorable conditions of waterflows, and to furnish a continuous supply of timber for the citizens of the United States. Demand by the American people to have certain lands of the unreserved public domain set aside was general. A number of areas in the Intermountain Region were made National Forests because of petitions from people in the arid valleys seeking to protect and improve the valuable mountain watersheds.

In addition to timber and water that occupied the attention of the people at the time the forest reserves were created, there were other valuable resources that could and should contribute to economic growth and the general welfare. Forage on the National Forests is especially important to the sheep and cattle industry of the mountain west. Demands for this resource had grown over the years. In fact, many areas had been seriously over-used by domestic livestock long before these lands were established as National Forests. Also, these mountain lands furnished excellent habitat for wildlife. They provided recreational opportunities and their use for this purpose has grown over the years.

THE GREATEST GOOD

Instructions were given in 1905 to Gifford Pinchot, Chief of the newly-launched Forest Service, by Secretary of Agriculture James Wilson that were fundamental and prophetic in scope.

> *In the administration of the forest reserves it must be clearly borne in mind that all land is to be devoted to its most productive use for the permanent good of the whole people . . . All the resources of forest reserves are for use, and this use must be brought about . . . under such restrictions only as will insure the permanence of these resources . . . and where conflicting interests must be reconciled the question will always be decided from the standpoint of the greatest good of the greatest number in the long run.*

This firmly established the policy of multiple use and sustained yield of the forest and range resources of the National Forests which has guided the Forest Service for more than fifty years. In 1960, the Congress of the United States formally recognized the importance of this policy and passed the Multiple Use-Sustained Yield Act. This law directs as a policy of the Congress that National Forests be administered for multiple use and sustained yield of their products and services.

The instructions and the multiple use law, however, did not specify how they could be carried out. How should the timber be cut and the forage grazed to assure perpetuity of these renewable resources? How should the forests be managed to protect the water supplies originating in the forests? Instructions did not spell out what forest and range practices were necessary to assure the attainment of that attractive and motivating slogan "the greatest good to the greatest number in the long run."

Important progress has been made in all phases of multiple use management of Intermountain wildlands since those early stalwarts launched the National Forest System. Through experience and research, forestry has come a long way on the road to coordination of resource uses and activities.

NEEDS OF THE FUTURE FROM WILDLANDS

On the basis of the knowledge we have gained by research and experience, we can see in general outline the picture of management and use of our wild lands for outdoor recreation, wildlife and fish, timber, range, and water purposes in the future. It looks good. We are sure there will be an increasing demand for these products and services. They will play an ever-increasing role in the economic, social, and spiritual growth of the people, and will be essential to that growth and will not be made obsolete by an atomic and chemical age.

Most of the timber stands of the Intermountain West are intact. In the harvesting of the trees, we will have the experience and knowledge that has been gained in the years past

and the new knowledge being supplied by research. To grow better wood, and grow it faster, we will employ the science of genetics and during the next centennial, trees improved through breeding and selection will be in production. The uses to which the wood of the forests will be put will be limited only by man's ability to manipulate the molecules of the cellulose.

Recreational use of our wildlands will increase beyond the imaginations of most of us. The uses of the woods, the streams, the lakes, and the mountains to satisfy the esthetic and spiritual needs of man have increased manyfold during the past fifty years and such needs will increase in geometric proportions during the next half century.

Range use reached the saturation point early in the history of western grazing, but the demand for forage for both livestock and game has steadily increased over the years. Although many adjustments in the numbers of animals grazed are yet to be made, rehabilitation of deteriorated rangelands through seeding and improved management practices gives promise of increased use in the future. Grazing of livestock and big game is the only means of harvesting the valuable forage crops that large areas in the West are capable of growing. Future plans must call for reaping this harvest from suitable rangelands on a sustained yield basis.

Water, the most essential product of wild lands, continues to be a critical need and will be a limiting factor to future development. Our rapidly growing population, with the need for more and more food, and the industrialization of all parts of the country are calling for more and better quality water. The multi-million dollar programs and plans for the development of our western rivers are of special interest to us now, and they illustrate the extent to which the public will go, and must go, in the development of its water supply. But dams alone will not do the job of water conservation. The forest and range lands on which the waters originate must be allowed to function to regulate streamflow and control sediment production.

All resource uses and activities must be based upon scientifically sound considerations of the hydrologic as well as the productive limits of the land. No one would think of building, or living in a house that would not withstand the impact of the strongest wind and the weight of the heaviest snow. We expect our houses, our bridges, and our dams to be adequately designed and safely built. The land also has definite limits of use beyond which productivity declines, accelerated erosion sets in, and the usefulness of streamflow diminishes. The capacity of these lands to withstand disturbance is indeed limited. These limits of the land to produce timber, forage, recreation, and to maintain normal stability of the soil and specific characteristics of streamflow, are not merely economic. They are physical and biological phenomena that operate without regard to market values.

CONSERVATION WITH USE

If forest and rangelands are to serve the Nation in the future they must be managed in such a way as to get the combination of uses of the resources which best meets the needs of the American people. We know, however, that the manner in which timber is cut and logged on the headwater slopes in Idaho or Wyoming is not solely the concern of the timber operator, but is of concern also to the public which has an interest in maintaining the useful life of reservoirs on the Columbia River and its tributaries in Washington and Oregon. We know, also, that the manner in which flocks are grazed on the high plateaus and the lower benchlands of Utah or Nevada is not solely the concern of the grazing permittee because even a little overgrazing can set in motion accelerated erosion that can doom downstream communities that are dependent upon water storage reservoirs.

Wildlife graze these same lands, and when their use of an area exceeds the grazing capacity, severe erosion can result. Declining deer or elk numbers are the concern of the sportsman, but too many animals on a watershed become the concern of all water uses. Recreationists, too, have a responsibility to avoid polluting water supplies and to prevent disastrous fires which could seriously damage whole watersheds.

The concept of conservation with use was

born in the minds of foresters many years ago, but full application of it must yet be put into effect. Sustained yield must be fully practiced because it is a fundamental and vitalizing concept of conservation. Sustained yield of forest and rangeland products, combined with watershed protection, must be an accepted goal in future wildland management.

Progress in the management and use of our forest and rangelands during the decades ahead, as we envision it, is predicated upon certain fundamental conditions. It will require enlightened public attitudes, more and better trained men, and the acquisition of additional knowledge through research. Experience tells us that education and research are basic. We live in a Republic where democratic processes must be fostered and protected. Research programs must be enlarged and strengthened. Although the general goals in wildland management have become clear, many methods and procedures, principles and concepts, must be worked out through scientific research and adopted by the users and managers of our wildlands before these goals can be reached.

The foundation for the practice of wildland management is strong, and designed to support the structure which will be built upon it. Sustained yield of wildland products and services at a high level without impairment of the productivity of the land is essential to the strength of the United States, at home and abroad, and to a rich and satisfying life for its people. Through coordinated effort of schools, public and private land-managing agencies, users of the forest and rangelands, and the public in general, this vision of the future can become a reality.

BIBLIOGRAPHY

Bailey, Reed W.

1935. Epicycles of erosion in the valleys of the Colorado Plateau Province. Journal of Geology, Vol. XLIII, No. 4, pp. 337-355.

....
1935. Shackling the mountain flood. American Forests, March 1935.

....
1938. Mountain waters. Intermountain Forest and Range Experiment Station, U. S. Forest Service.

....
1941. Climate and settlement of the arid region. Yearbook of Agriculture 1941. U. S. Dept. Agri.

....
1941. Land erosion — normal and accelerated —in the semiarid West. Transactions, American Geophysical Union, 1941, 11 pp.

....
1945. Determining trend of range-watershed condition essential to success in management. Journal of Forestry, Vol. 43, No. 10, pp. 733-737.

....
1948. Geologic understanding and watershed management. Inter-American Conference on Conservation of Renewable Natural Resources, Dept. of State Denver, Colorado. September 1948.

....
1958. Living in harmony with nature. Utah Educational Review, May 1958, 4 pp.

....
1959. The coming challenge to watershed management in the Northwest. Oregon State University, Corvallis, Oregon. 9 pp.

................**, and Copeland, Otis L., Jr.**
1960. Low flow discharges and plant cover relations on two mountain watersheds in Utah. Publication No. 51 of the I.A.S.H. Commission of Surface Waters, pp. 267-278.

........................**, and** ....
1961. Vegetation and engineering structures in flood and erosion control. Proceedings of 13th Cong. Int. Union of For-Res. Organizations. Vienna, Austria, 23 pp.

....................**, Craddock, George W., and Croft, A. R.**
1947. Watershed management for summer flood control in Utah. U. S. Dept. Agri. Misc. Pub. No. 639.

......................, and Croft, A. R.
1937. Contour-trenches control floods and erosion on range lands. U. S. Dept Agri. Forestry Pub. No. 4.

......................, Forsling, C. L., and Becraft, R. J.
1934. Floods and accelerated erosion in Northern Utah. U. S. Dept. of Agri. Misc. Pub. No. 196.

Baker, F. S.
1917. Some field experiments on evaporation from snow surfaces. Monthly Weather Review, July 1917. pp. 363-366.

....
1944. Mountain climates of the Western United States. Ecological Monographs 14, April, 1944, pp. 223-254.

Bates, C. G., and Henry, A. J.
1928. Forest and stream-flow experiment at Wagon Wheel Gap, Colorado. U. S. Dept. Agri. Monthly Weather Review, Supplement No. 30.

Bowman, Isaiah
1937. Headwaters control and use—influence of vegeattion on land-water relationships. Proc. Upstream Engin. Conf. Washington, pp. 76-95.

Bradley, John H.
1935. Autobiography of Earth. Coward-McCann, Inc., N. Y.

Brown, Carl B.
1944. The control of reservoir silting. U. S. Dept. Agri. Misc. Pub. No. 521.

Bryan, Kirk
1940. Erosion in the valleys of the southwest. New Mexico Quarterly, November 1940, pp. 227-232.

Bullard, W. E.
A review of soil freezing as affected by snow cover, plant cover and soil conditions in Northwestern United States. Publication n° 39 de l'Association Internationale d'Hydrologie (Assemblee generale de Rome, tome IV) pp. 132-136.

Cannon, S. Q. (chairman)
1931. Torrential floods in northern Utah. Report of Special Flood Commission, circular 92, Utah Agri. Expt. Sta., Logan, Utah.

Carhart, Arthur H.
1951. Water or your life. Lippincott, New York.

Chamberlin, T. C.
1908. Soil wastage. Proceedings of Conference of Governors on Conservation of Natural Resources, House Document 1425, 60th Congress, 2d session, Washington, D. C., pp. 75-83.

Clyde, George D.
1931. Snow-melting characteristics. Bulletin 231. Utah Agricultural Experiment Station.

Colman, Edward A.
1953. Vegetation and watershed management. The Ronald Press, N. Y.

Cottam, Walter P.
1961. Our renewable wild lands — a challenge. University of Utah Press, Salt Lake City, Utah.

Craddock, George W.
1945. Salt Lake City flood, 1945. Utah Academy of Sciences, Arts and Letters, Vol. 23, pp. 51-61.

......................, and Pearse, C. Kenneth
1938. Surface runoff and erosion on granitic soil of Idaho as influenced by range cover, soil disturbance, slope, and precipitation intensity, U. S. Dept. Agri. Cir. 482.

Croft, A. R.
1944. Evaporation from snow. Bull. of the Amer. Met. Soc., Vol. 25, pp. 334-337.

....
1944. Snow melting and evaporation. Science N. S., Vol. 100, No. 2591. pp. 169-170.

....
1946. Some factors that influence the accuracy of water-supply forecasting in the Intermountain Region. Trans. American Geophysical Union, Vol. 27, pp. 375-388.

....
1948. Water loss by stream surface evaporation and transpiration by riparian vegetation. Trans. American Geophysical Union, Vol. 29, No. 2, pp. 235-239.

....
1961. Some aspects of manipulating vegetation to increase water yield. Proceedings, Watershed Management Study Conference, U. S. Forest Service and University of Idaho, pp. 56-64.

....
1962. Some sedimentation phenomena along the Wasatch Mountain Front. Journal of Geophysical Research, Vol. 67, No. 4, pp. 1511-1524.

.................., and Ellison, Lincoln
1960. Watershed and range conditions on Big Game Ridge and vicinity, Teton National Forest, Wyoming| U. S. Forest Service, Ogden, Utah.

......................., and Goodwin, Victor
1956. Some flood characteristics of Sierra Nevada east front watersheds. Proceedings, Tenth Nevada Water Conference, pp. 12-17.

.................., and Marston, Richard B.
1943. Some recharge phenomena of a Wasatch Plateau watershed. Trans. American Geophysical Union, pp. 461-465.

.........................., and ....
1950. Summer rainfall characteristics in Northern Utah. Trans. American Geophysical Union, Vol. 31, No. 1, pp. 83-95.

..............., and Monninger, L. V.
1953. Evapotranspiration and other water losses on some aspen forest types in relation to water available for stream flow. Trans. American Geophysical Union, Vol. 34, No. 4, pp. 563-574.

Ellison, Lincoln, Croft, A. R., and Bailey, Reed W.
1951. Indicators of condition and trend on high range-watersheds of the Intermountain Region. U. S. Dept. Agri. Agriculture Handbook No. 19, August 1951.

Fonda, Morris E.
The Lord's land. The Sears-Roebuck Foundation, Chicago, Ill.

Forest Service
Annual reports. Intermountain Forest and Range Experiment Station, Ogden, Utah, and Rocky Mountain Forest and Range Experiment Station, Ft. Collins, Colo. U. S. Forest Service.

....
1948. How forest conditions affected the 1948 Columbia flood. U. S. Dept. Agri. AIB No. 10.

Forsling, C. L.
1931. A study of the influence of herbaceous plant cover on surface runoff and soil erosion in relation to grazing of the Wasatch Plateau Utah. U. S. Dept. Agri., Tech. Bull. No. 220.

Frank, Bernard and Netboy, Anthony
1950. Water, Land & People. Alfred Knoff, New York.

Goodell, Bertram C.
1958. A preliminary report on the first year's effects of timber harvesting on water yield from a Colorado watershed. Rocky Mountain Forest and Range Experiment Station, U. S. Forest Service, Station Paper No. 36.

Gregory, Herbert E.
1938. The San Juan County, U.S.G.S. Prof. Paper No. 188.

Kittredge, Joseph
1948. Forest influences. Mc-Graw-Hill, N. Y.

Krutch, Joseph W.
1955. Conservation is not enough. The American Scholar, Vol. 23, No. 3, pp. 265-305.

Lassen, Leon; Lull, Howard W., and Frank, Bernard
1952. Some plant-soil-water relations in waatershed management. U. S. Dept. of Agri., Cir. No. 910.

Leopold, Aldo
1949. A sand county almanac. Oxford University Press. N. Y.

Lord, Russell
1938. To hold this soil. U. S. Dept. of Agri., Misc. Pub. No. 321.

Love, L. D.
1960. Management of alpine and subalpine mountainous areas for water yield. Fifth Annual New Mexico Water Conference, pp. 39-44.

Lowdermilk, Walter C.
1940. The eleventh commandment. American Forests, January 1940.

....
1959. Conquest of the land through seven thousand years. U. S. Dept. Agri., Agriculture Information Bull. No. 99.

Lull, Howard W. and Ellison, Lincoln
1950. Precipitation in relation to altitude in Central Utah. Ecology, Vol. 31, No. 3, pp. 479-484.

Marsh, George P.
1861. The earth as modified by human action. Scribner-Armstrong, & Co., N. Y.

Marston, Richard B.
1952. Ground cover requirements for summer storm runoff control on aspen sites in northern Utah. Journal of Forestry, Vol. 50, No. 4, pp. 303-307.

Meeuwig, Richard O.
1960. Watersheds A and B — a study of surface runoff and erosion in the subalpine zone of central Utah. Journal of Forestry, Vol. 58, No. 7, pp. 556-560.

Megahan, Walter F., and Satterlund, D. R.
1961. Winter infiltration studies on abandoned and reforested fields in central New York. Proceedings Eastern Snow Conference, pp. 121-132.

Noble, Edward L.
1963. Sediment reduction through watershed rehabilitation. U. S. Dept. Agri., Forest Service, Int. Region, Ogden, Utah

Osborne, Fairfield
1948. Our plundered planet. Little, Brown & Co., N. Y.

Packer, Paul E.
1951. An approach to watershed protection criteria. Journal of Forestry, Vol. 49, No. 9, pp. 639-644.

Paton, Alan
1950. Cry the beloved country. Charles Scribner's Sons, New York.

Paul, J. H., and Baker, F. S.
1925. The floods of 1923 in Northern Utah. Bulletin of the University of Utah, Vol. XV, No. 3.

Price, Raymond, and Evans, R. B.
1937. Climate of the West Front of the Wasatch Plateau in Central Utah. U. S. Dept. Agri., Monthly Weather Review.

Reno Junior Chamber of Commerce
1950. Reno Flood 1950. Reno Junior Chamber of Commerce, Reno, Nevada.

Renner, F. G.
1936. Conditions influencing erosion, on the Boise River Watershed, U. S. D. A., Tech. Bul. 528.

Rich, L. R.
1960. Preliminary effects of forest tree removal on water yields and sedimentation. Proceedings of Fourth Annual Arizona Watershed Symposium, pp. 13-16, State Land Dept., Phoenix.

Rowe, P. B., and Reimann, L. F.
1961. Water use by brush, grass, and grass-forb vegetation. Journal of Forestry, Vol. 59, No. 3, pp. 175-181.

Sears, Paul B.
1937. Deserts on the march. University of Oklahoma Press, Norman, Oklahoma.

Shaler, Nathaniel S.
1905. Man and the Earth. Dodd, Mead & Co., Inc., N. Y.

Shephard, Ward
1945. Food or famine. The Challenge of Erosion. The Macmillian Co., N. Y.

....
1945. Rebuilding the Rio Grande, U. S. Department of Interior Report.

Stevens, J. C.
1936. The silt problem. Amer. Soc. Civil Engineers, Transactions 101: pp. 207-228.

U. S. Department of Agriculture
1950. Mount Pleasant Flood of July 24, 1946. Flood Control Survey Report — Sevier Lake Watershed, Appendix No. 5.

West, Allan J.
1962. Snow evaporation from a forested watershed in the central Sierra Nevada. Journal of Forestry, Vol. 60, No. 7, pp. 481-484.

Wilm, H. G., and Dunford, E. G.
1948. Effect of timber cutting on water available for stream flow from a lodgepole pine forest. U. S. Dept. of Agri. Tech. Bull. No. 968.

There is a lovely road that runs from Ixopo into the hills. These hills are grass-covered and rolling, and they are lovely beyond any singing of it. . . .

The grass is rich and matted, you cannot see the soil. It holds the rain and the mist, and they seep into the ground, feeding the streams in every kloof. It is well-tended, and not many cattle feed upon it; not too many fires burn it, laying bare the soil. Stand unshod upon it, for the ground is holy, being even as it came from the Creator. Keep it, guard it, care for it, for it keeps men, guards men, cares for men. Destroy it and man is destroyed.

Where you stand the grass is rich and matted you cannot see the soil. But the rich green hills break down. They fall to the valley below, and falling, change their nature. For they grow red and bare; they cannot hold the rain and mist, and the streams are dry in the kloofs. Too many cattle feed upon the grass, and too many fires have burned it. Stand shod upon it, for it is coarse and sharp, and the stones cut under the feet. It is not kept, or guarded, or cared for, it no longer keeps men, guards men, cares for men. The titihoya does not cry here any more.

The great red hills stand desolate and the earth has torn away like flesh. The lightning flashes over them, the clouds pour down upon them, the dead streams come to life, full of the red blood of the earth. Down in the valleys women scratch the soil that is left, and the maize hardly reaches the height of a man. They are valleys of old men and women, of mothers and children. The men are away, the young men and girls are away. The soil cannot keep them any more.

From CRY, THE BELOVED COUNTRY by Alan Paton
(Charles Scribner's Sons, 1948)